University of OSLO
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GIS AND DESIGNING MAPS FOR MALARIA MANAGEMENT: **The case of Tigray in Ethiopia**

Masters Thesis

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This work is dedicated to the memory of my mother.

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ABBREVIATIONS

ART	Anti-Retroviral Therapy
CSA	Cenral Statistical Agency of Ethiopia
CHW	community health workers
ESRI	Economic and Social Research Institute
FAO	Food and Agriculture Organization
GIS	Geographical Information System
GPS	Global Positioning System
MARA	Mapping Malaria Risk in Africa
MIS	Malaria Information systems
MOH	Minstry of Health
MOI	Minstry of Information
Region	National regional State
Tabia	Locality, most peripheral administrative unit in Ethiopia
TB	Tuberculosis
TPLF	Tigray People Liberation Front
TRBH	Tigray Region Bureau of Health
UTM	Universal Transverse Mercator
Wereda	District, administrative unit with population of about 97,000
WHO	World Health Organization
Zone	Geographic administrative unit

1. Introduction

1.1. Background

Malaria is a serious mosquito-borne disease causing global concern. About 3.3 billion people - half of the world's population are at risk of malaria. Every year, this leads to about 250 million malaria cases and nearly one million deaths (WHO, 2009). Around 90% of these deaths occur in Africa mostly in young children. In Africa one in every five (20%) childhood deaths is due to the effects of malaria disease and an African child has on average between 1.6 and 5.4 episodes of malaria fever each year (WHO, 2009 & FMOH website source) .

In Ethiopia almost 75 percent of the land is malarious and an estimated 68 % of the total population lives in areas at risk of malaria (CSA, 2005). In 2006 Ethiopia had approximately 4% of all cases in the African Region (TRBH, 2007). Geographically, malaria is present everywhere except in the central highlands of the country and its transmission is unstable, depends on both latitude and rainfall. The malaria transmission season runs from September to December, following the major rainy season from June to August, with a minor transmission season from April to May in areas that receive rains during the short rainy season from February to March. Localized or widespread malaria epidemics can occur during the transmission season. Generally areas at altitude below 2000 meters above sea level are considered malarious. However, local transmission has also been detected in areas at altitudes as high as 2,500 meters (CSA, 2005). In 2003 malaria epidemic had affected 211 districts where more than 2 million clinical cases were recorded (*ibid*).

In Tigray (the case study area) the majority of the region lies within altitude range of less than 2000 m above sea level. More precisely according to United States Geological Survey (USGS) digital elevation model 78% of the districts majority terrain lies within less than 2000 meters above sea level (TRBH website, access 10, 12, 2010). According to WHO report (2005), 85% of its estimated 3.6 million populations are rural, and 56% live in malarious areas, while 50 percent live beyond the reach of any healthcare facilities. As in the rest of Ethiopia, malaria is unstable in Tigray. Transmission is seasonal and depends on both latitude and rainfall. It also varies widely with complex topography, which ranges from high altitude and mountainous terrain, to deeply incised river valleys, to low altitudes fertile valleys.

In most areas of the region the population is non-immune and even low level parasitaemiabis associated with clinical illness (WHO, 1999). This makes the prevalence of malaria infection and clinical illness similar in all age groups. Prevalence of infection tends to be higher in males, possibly because herding and farming (Crop surveillance) required outdoor work during mosquito biting times.

The Regional Government of Tigray in collaboration with WHO has responded by designing a Community –Based, malaria control Program based on village health workers. Large majority of the members of the community health workers (CHWs) are adult males, farmers' residents in the village and almost 90% of them treat Patients in their homes. In addition to this in 1992 the Malaria Control Program in the region introduce mapping & geographic information systems technology to support its community based malaria control program with the aim of trying to spatially analyse malaria distribution in the region and to monitor the coverage of the community based control activities in relation to population at risk (Ghebreyesus et al. 1999).

In order to properly plan, manage and monitor any public health program, it is vital that up-to-date and relevant information is available to decision-makers at all levels of the public health system. As every vector-borne disease control requires a different response and policy decision, information must be available that reflects a realistic assessment of the situation at local, national and global levels. This should be done with best available data and taking into consideration disease transmission dynamics, demographics, availability of and accessibility of existing health and social services as well as other geographic and environmental features.

Geographic information systems (GIS) provide ideal platforms for the convergence of disease specific information and their analyses in relation to population settlements, surrounding social and health services and the natural environment. They are highly suitable for analyzing epidemiological data, revealing trends and interrelationships that would be more difficult to discover in tabular format. Moreover, GIS allows policy makers to easily visualize problems in relation to existing health and social services and the natural environment and so more effectively target resources.

Geographic information system is an ideal information system in malaria management, since the occurrence of malaria is influenced by numerous phenomena outside the habitual framework of the health systems including environmental changes, topography, temperature, rainfall, land use and degree of deforestation (Spie & Dale, 2003). Each of those different types of data and information has a spatial basis. This makes GIS ideal information systems to be used in malaria management since it is the best system in our generation which deals with geographic aspect of information.

The contribution of GIS and GIS mapping techniques in malaria management and malaria control program includes creating a practical operational maps which can assist in resource allocation, to be used as analytical tools that can facilitate program monitoring and evaluation and as a research tool to help in investigating various spatial aspects of malaria epidemiology (Sweeney, 1998). Currently GIS has being used in malaria control and research program for mapping malaria incidence /prevalence, mapping the relationships between malaria incidence/prevalence and other potentially related variables, in Modeling malaria future risk, and as innovative methods of data collecting tool (remote sensing) .

For example, GIS was used to develop an atlas of malaria in Africa which contains relevant information for rational and targeted implementations of malaria control by a non-institutional project called MARA/ARMA (MARA 1998). In southern area of Chiapas, Mexico GIS were used to identify villages at high risk for malaria transmission using remote sensing based models (Beck et al. 1997). GIS have also been used to explore the impact of the intervention coverage and people's adherence to the intervention on malaria health outcome among targeted villages in various geographic locations in Laos, Southeast Asia in Khammouane Province (Shirayama et al. 2009) .

In all of the above examples and so many more studies that have been used GIS and GIS mapping technique for malaria control, different maps are produced in order to present their study findings. However to the best of our knowledge this is the first of its kind that have been done in identifying and developing useful types of maps in malaria research and control program and strictly follow and discuses map design principles and practices in the output of GIS mapping particularly in malaria field.

In addition to that, even though GIS technology has been introduced to malaria control program in Tigray, there are no much published documentation on the implementation and success use of it in the region. In fact the few published papers, for example a study done to assess the impact of construction of micro dams on the incidence of malaria by Ghebreyesus et al. (1999) and a similar paper in title ‘Pilot studies on the possible effects on malaria of small-scale irrigation dams’ by Ghebreyesus et al. (1998) haven’t used GIS technology for their studies. On our review of the published papers and annual reports of the Regional Health Bureau, we found out that the use of GIS and its mapping technique hasn’t been exploited in the region. Majority of the research papers in the case of Tigray in relation to malaria and the annual reports use tables and graphs to present their finding and the malaria data, While maps are the best visualization methods to communicate, interpret, and explain spatially related data. Maps aid in the visualization of differences, clustering, heterogeneity, or homogeneity within data (spie & Dale ,2003). Spatial patterns can be perceived and correlations can be visualized through the use of maps. Symbols and colors can communicate detail or the relative importance of certain features (Dent 1999). Malaria control program staff tends to be familiar with maps, using them for their daily activities (Spie& Dale 2003). Maps can consequently be used to communicate ideas and explanations about the determinants of malaria and strategies of control. Maps can also be exploited as the medium of communication between a control program and the public.

1.2 Research Objectives

On this backdrop, the main aim of this research was to explore the use of GIS and GIS mapping technique in malaria management in order to find out how they can be of use in supporting and strengthening malaria management and control program. Mainly, the rationale behind this study is to demonstrate the powerfulness of maps in visualizing the results of processed and analyzed data in malaria management and show an effective way of designing those in order to convey the proposed appropriate message.

Research questions

1. What type of maps can be designed for malaria management program?
2. How can the maps be designed effectively & efficiently in order to convey the proposed appropriate message?

To answer these questions the study specifically aimed at utilizing the data gathered from the Tigray regional bureau of health in mapping:

1. Basic health care access information
2. Geographic distribution of the disease (malaria)

3. Potentially related variables in relation to malaria incidence/prevalence
4. The trend of malaria
5. Prevention and intervention information
6. The trend of prevention and intervention information

Therefore, far beyond the academic benefits that the researcher might explore, this study paper (thesis) will have its own significant contribution in the quest to fight against malaria in Tigray by visualizing and analyzing malaria data using GIS and it can serve as a policy guidance to the Tigray regional State in assisting malaria control and prevention program. In addition to that , the study can contribute to the handful literature about GIS and GIS mapping in Ethiopia particularly in malaria research.

1.3 Motivation

I was looking for a research topic for my master's thesis and at first I come up with different ideas. But looking and the classes I attend on my maters program, I realize that there was no any other word that has been mentioned more often in almost all classes & syllabi than those two words, 'health & information Systems'. This strike my mind to ignore the thesis topic I listed before and to look on the health problems in my country Ethiopia particularly in Tigray region where I come from. In just few minutes of my search on the web, I understood the severity of malaria in the region and the country at large. Then this leads me to search the type of information systems that are widely applied in malaria. This was when I realized that GIS is the ideal information system which is currently being used in public health and in malaria worldwide. But on my search on the work of GIS in relation to malaria in Tigray, there is no much practically published documentation on the adoption and success use of it in the region. Most importantly I found out that the studies done in the region does not exploit the potential of GIS. In addition to that, mostly the malaria control department and the ministry of health in the region use table and graphs to present their analyzed data. While, some of the data are with spatial dimension for example (distribution of the disease in the whole districts of the region) could have been presented in a more communicable and powerful way using maps.

Additionally, Literatures like Tanser & Sueur (2002) found out that most health related applications of GIS were done in South Africa thereby raising questions on the level of its application in other Sub Saharan Africa nations and I myself have found no complete literature on GIS mapping in malaria management. Therefore, another motivating factor for this research is the quest to contribute to literature about GIS and GIS mapping in Ethiopia particularly in malaria research.

1.4 Targeted audience of this research

The results of this research are expected to be useful to anyone who is interested in GIS and GIS mapping in malaria area. But the main intended audience of this research work are Malaria managers, Malaria researchers, Public health managers and the general public.

1.5 Structure of the thesis

This thesis is divided into eight chapters. Chapter 2 discusses the context in which the research was based on and consists of the general profile of Ethiopia, its health status, geographic, demographic, climatic features and malaria situation-analysis of the country. Chapter 3 is reviews the relevant literature used on this research, which consist of information systems, geographic information systems, GIS in public health, GIS in malaria, and principle of cartography in map designing. Methods and data are discussed in chapter 4, which includes the research framework of this study. Chapter 5 and chapter 6 are devoted to present and discuss in detail the design process in constructing the maps and useful types of maps for malaria management consecutively. Chapter 7 discuses the critics and evaluation of the initial maps based on the map design principles and feedback from one target group (malaria experts). Chapter 8 is reserved for the summary and conclusion of the study .

2. Background of the Study Area

This chapter presents the context in which the research was carried out. It presents the general profile of Ethiopia (Geographic, climatic and socio-demographic status) , its health status , followed by an in-depth description of the case in the study area - Tigray Regional State of Ethiopia

2.1 Geo-climatic profile

Ethiopia is situated in the Horn of Africa between 3 and 15 degrees north latitude and 33 and 48 degrees east longitude. It is a country with great geographical diversity; its topographic features range from the highest peak at Ras Dashen, which is 4,550 meters above sea level, down to the Affar Depression at 110 meters below sea level (CSA, 2000). The climatic condition of the country varies with the topography, with temperatures as high as 47 degrees Celsius in the Afar Depression and as low as 10 degrees Celsius in the highlands. The total area of the country is about 1.1 million square kilometers and Djibouti, Eritrea, Sudan, Kenya, and Somalia border it . A large part of the country is high plateau and mountain ranges, with steep edges dissected by rushing streams of tributaries of famous rivers like the Abay (The Blue Nile), Tekeze, Awash, Omo, the Wabe Shebelie and the Baro-Akobo (MOI, 2004 as cited in EDHS,2005).

There are three principal climatic groups in Ethiopia, namely the tropical rainy, dry, and warm temperate climates. In Ethiopia the mean maximum and minimum temperatures vary spatially and temporally. Generally, the mean maximum temperature is higher from March to May and the mean minimum temperature is lower from November to December as compared to the other months (EDHS, 2005). The general pattern of annual rainfall distribution in the country also remains to be seasonal, varying in amount, space, and time (MOI, 2004 as cited in EDHS,2005). Due to this diverse topography and climatic conditions of the country, epidemiology of malaria is more unstable than in any other country in Africa.

2.2 Socio-demographic profile

Ethiopia's population has been growing at a rate of 2.6% or by an increment of 2 million persons annually (FMOH,2010 website) . With a total population of 79 million in 2008 (2000

EFY), it has become the second most populous country in Africa, following Nigeria. At such growth rate, the population is expected to reach 82.1 million by the year 2009 (FMOH, 2010). Half of the population (50.1%) is female. The average household size is 4.8. Out of the total population, 85% lives in rural areas.

The country's economy is highly dependent on agriculture through which 85 % of the populations earn their livelihoods. The agriculture sector respectively accounts for half of the GDP and 60% of the exports nationally. Coffee and skin are key agricultural products, but remain vulnerable to drought and poor cultivation practices. High donor dependency is an outcome of the country's attempts to address this vulnerability. In November 2001, Ethiopia qualified for debt relief from the Highly Indebted Poor Countries (HIPC) initiative, and in December 2005 the IMF forgave Ethiopia's debt (World Fact Book ,2010). Under Ethiopia's constitution, the state owns all land and provides long-term leases to the tenants; the system continues to hamper growth in the industrial sector as entrepreneurs are unable to use land as collateral for loans (World Fact Book, 2010). Drought struck again late in 2002, leading to a 3.3% decline in GDP in 2003. Although GDP growth has since rebounded, soaring commodity prices in 2007 and 2008 and the global economic downturn led to balance of payments pressures, partially alleviated by recent emergency funding from the International Monetary Fund (IMF).

In the country as a whole, there are more than eighty languages spoken. Among those, Amharic, Oromiffa, Tigrigna and Somali are spoken by the majority of the population. Official government documents are available both in Amharic and English. In the health sector, most of the reporting formats and written documents are available in their English version.

2.3 Administrative Structure

The Ethiopian constitution, introduced in 1994 created a federal government structure. The federal structure is composed of nine Regional States: Tigray, Afar, Amhara, Oromia, Somali, Benishangul Gumuz, Southern Nations Nationalities and Peoples Region (SNNPR), Gambella and Harrari and two city Administrations Addis Ababa and Dire Dawa .

The National Regional States and City Administrations are further divided into 611 woredas. Woreda is the basic decentralized administrative unit and has an administrative council composed of elected members. The 611 woredas are further divided into roughly 15,000 Kebeles organized under peasant associations in rural areas (10,000 Kebeles) and urban dwellers associations (5,000 Kebeles) in towns (MOH ,2004).

At its outset, the Ethiopian constitution grants the regional states the status of a nation, and they are given rights of self-determination up to secession. The regional states have their respective autonomous governments set up under proclamation No. 7/1992. Each regional government includes a State Council (the highest organ of state authority) and a State Administration (highest organ of executive power). The State Council plans, approves, leads and controls economic and social development programmes. The State Administration is the highest executive authority of the regional government and is elected by the State Council and includes 15 Executive Committee members. The ethnic groups are represented in the House of Federation whose members are elected by the state councils.

With the devolution of power to regional governments, public service delivery, including health care, has to a large extent fallen under the jurisdiction of the regions. The approach has been to promote decentralization and meaningful participation of the population in local development activities. For administration of public health care, there is a Regional Health Bureau (RHB) at the Regional level. Due to the Government's commitment to further decentralize decision-making power, woredas are currently the basic units of planning and political administration.

2. 4 Health status in Ethiopia

Ethiopia has a poor health status relative to other low-income countries, even within Sub-Saharan Africa. Infectious and communicable diseases account for about 60-80% of the health problems in the country (EDHS,2010). Widely spread poverty along with low income levels of the population, low education levels (especially among women), inadequate access to clean water and sanitation facilities and poor access to health services have contributed to the high burden of ill-health in the country. Average life expectancy at birth is also relatively low at 48 (47 for males and 49 for females). Poor nutritional status, infections and a high fertility rate, together with low levels of access to reproductive health and emergency obstetric services, contribute to one of the highest maternal mortality ratio in the world, which is 871/100,000 live births (FMOH 2010).

This situation is further aggravated by the high population growth. The Young constitute one third of the total population in Ethiopia(EDHS,2005). This implies a profound reproductive health needs. The major reproductive health problems faced by the young population in the country are gender inequality, early marriage, female genital mutilation, unwanted pregnancy, closely spaced pregnancy, unsafe abortion, and Sexually Transmitted Diseases (STDs) including HIV/AIDS.

According to MOH (2009), HIV epidemic has stabilized in the country with HIV prevalence estimated at 2.2% in 2003/2004 and 2.1% in 2006/07 and 2007/2008. As far as malaria epidemic is concerned, it remains as the major cause of morbidity as well as mortality in the country. In the same document, a study conducted in early 2001 indicated that only 31% of cases of fever seen in the health facilities were properly managed ; only 7% of children with malaria received early diagnosis and treatment and the case fatality rate was 5.5%.

There is a very high unmet health care need in Ethiopia that needs to be addressed through rapid expansion of Primary Health Care (PHC) services. Since 1991 the goverment has been upgrading general health services through rehabilitation and construction of health facilities, deployment of health personnel, and expansion of primary health care. As of December 2008 a total of 11,446 health posts(HP) had been constructed and 3,576 is planned to be constructed by the end of 2009, against the overall target of 15,000 HP. Similarly, from the total required HP, 5,106 of them have been fully equipped with a plan to equip 9,916 by the end of 2009 (EDHS,2005).Health centers mainly provide basic curative health care services but also support Health Extension Program by acting as referral and technical assistance centers for Health Extension Workers. In Ethiopia, even though a health center is needed for every 25,000 people, there were only 668 health centers at the end of 2006/07(MOH ,2010). To achieve the planned universal primary health care coverage, federal ministry Of Health (FMoH) aims to have 3,200 health centers (HCs) in place by 2010. As of July 2010, a total of 2,104 HCs were available nation-wide. The Government has committed to fully finance the construction of 2,951 additional HCs, over 695 of which are currently under construction (FMHO, 2010).

2.5 Tigray Regional State: *Geographic, demographic and climatic features*

Tigray is the north most national regional states of Ethiopia and is located between latitude 12 degree and 15 degree north. The region is divided into north-western and southern lowlands (700-1500) meters above sea level) and the central Highlands (1500-3000 meters above sea level).The majority of the region lies within altitude range of less than 2000 m above sea level, more precisely according to United States Geological Survey (USGS) digital elevation model 78% of the districts' majority terrain lies below 2000 meters above sea level (TRHB website). Average temperatures ranges from about less than 16 °C at higher altitudes to 22 °C in areas below 2,400 meters. The region covers 54,572.6 square kilometres and the projected population in 2008 was 4,831471 including 2,079,890 children under 15 years old , (TRHB annual report, 2008) .Estimated growth rate is at 3% per year.

Tigray's agriculture is based on plough cultivation of mainly cereal crops withTeff, wheat, and barely as the main crops and until recently depended almost entirely on rainfall. The main rainy season is from May to September, with most rains falling in June and July. In south-eastern Tigray additional rains fall during January and February, providing sufficient moisture for a second harvest (DHS,2000).

Administrative Structure

The State of Tigray consists of 6 administrative zones (See figure 2.1) , one special zone, 35 woredas and 74 towns. The State Council which is the highest administrative body of the state is made up of 152 members and the executive body comprises of 16 personalities. The region shares common borders with Eritrea in the north, the State of Afar in the east, the State of Amhara in the south, and the Republic of the Sudan in the west.

Health Status

Infectious diseases and nutritional problems are major health problems of the Region and account for the majority of all health problems. Malaria, tuberculosis (TB), acute respiratory tract infection (ARI), diarrhea and HIV/AIDS are among the top ten disease burdens in theRegion (Tigray Health Profile, 2008). Tigray Region health services are provided predominantly by the government. There are some institutions owned privately and by non-governmental organizations (NGOs).

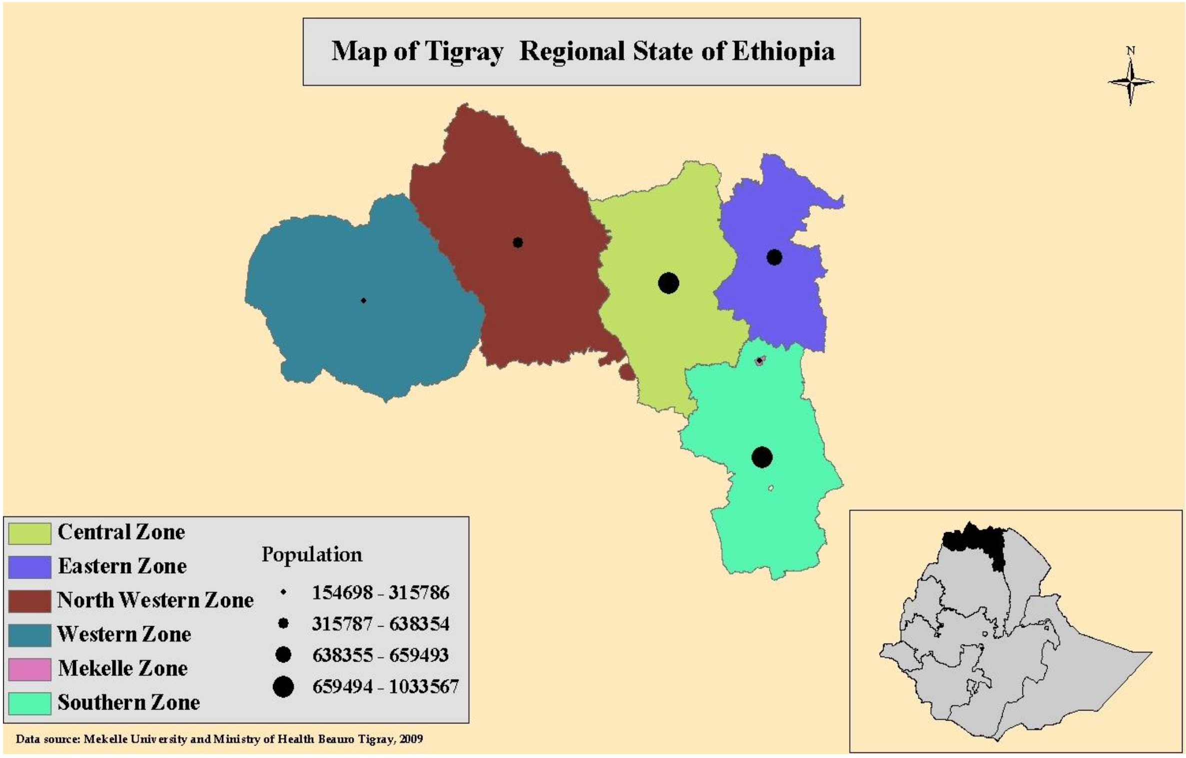

Figure 4.4 Map of the Tigray Regional State of Ethiopia

The Region's socio-economic and health problems are immense and highly interrelated. Development without healthy people is unthinkable; the health sector is considered as the integral target of development by the Regional government. Since 1991, there has been an upgrading of general health services through rehabilitation and construction of health facilities, training and deployment of health personnel, and expansion of primary health care. As a significant proportion of the population still live beyond the catchments areas of even peripheral health institutions, community-based volunteer health workers continue to play an important part in delivery of primary health care services (Tigray Health Profile, 2008).

Tigray Malaria situation-analysis

Tigray region is endemic to malaria. Almost 75% of the region is malarious, and about 56 % of the population lives in malarious areas (TMOH, website 2010). As the rest of Ethiopia, malaria is unstable and transmission is seasonal and depends on both altitude and rainfall. Transmission varies widely with the complex topography which ranges from high altitude plateau and mountainous terrain, to deeply incised river valley and canyons, to low altitude semi-arid plains or fertile valley in the region. Malaria transmission usually occurs at altitudes below 2000 meters above see level, and 78% of the region lies in this range (TRBH website).The unstable nature of malaria makes the region prone to outbreaks, and makes malaria a major public health problem in the region. The major malaria vector in the region is Anopheles gambiae, which breads in small sun exposed polls mainly produce during the rains (WHO review, 1999). Development of the malaria parasite within the vector, and vector prolonged existence depend on both temperature and relative humidity (WHO review, 1999).

As of Ethiopia, the control of malaria in Tigray has a history of four decades (WHO review, 1999). However, during the Ethiopian civil war which took 17 years from 1976 to 1991, government services in the region were gradually suspended as the region became the stronghold of the Tigray People's Liberation Front (TPLF). During this time, in the place of formal government services, the TPLF established village and district level government based on direct participation of communities. This includes a primary health care system based on village health workers. At the end of the war a large number of those community health workers became inactive, and due to this malaria became the leading cause of morbidity and mortality in the region (Ghebreyesus, 1999). For this reason in 1992 the government of Tigray decided to revitalize the activity of the community health workers (CHWs) and designed a community-based malaria control program in collaboration with WHO (Ghebreyesus et al, 1999).

CHWS are trained volunteers who are responsible for general health and malaria activities in a locality (tabia) of about 25000 people. The large majority of the members of CHWs are adult males, farmers' residents in the village. Almost 90% of them treat Patients in their homes. The main responsibility of the CHWs includes diagnosis of uncomplicated malaria based on clinical signs and symptoms, treatment with chloroquine according to age, detection and referral of severe cases and referral of still sick patients (Ghebreyesus et al, 1999).

Following the introduction of the community-based program, a significant decrease which is around 40% in death rates of children under 5 was reported from 1994 to 1996 in mortality surveys covering random samples of 7,335 and 10,567 children, respectively. However the reduced levels were not maintained and a 10% mortality increase was documented in 1998, using the same survey methodology (WHO review, 1999). Malaria deaths increased in 1997/1998. According to WHO review of (1999) in spite of improved coverage, a significant portion of children under 5 do not have access to the CHWs, and all three mortality surveys showed that 45-52% children who died received no medical care.

Since the establishment of the millennium development goal in 2000, the regional health bureau of Tigray have been designing a 5 years strategic plan and revising the plan continuously. One o f the goals of the Tigray regional health bureau that was stated in the 5 year strategic plan for 2004 to 2006 was to reduce malaria prevalence by 25%, but as opposed to the 5 year strategic plan the increase trend of malaria incidence was detected in 2005 , in fact in one of the districts (Raya Azebo) a focal epidemic has occurred (TMOH annual report, 2005). According to the annual report the possible reason for the increase of malaria morbidity and Malaria incidence in 2005 is, over the previous 3 years, Ethiopia has been implementing a policy of food security through voluntary resettlement from the highland areas to the lowland western regions; In Tigray the movement is from eastern, southern and central Tigray to the western qolla regions. And until 2005, 150,000 people were resettled in Tigray alone. This huge population movement of semi-immune population adds vulnerability to malaria. Second, also related to the development policy of the government, farmers everywhere were asked to harvest water particularly using open surface ponds. In Tigray alone, 90,000 such ponds were dug and they contributed to at least one epidemic of malaria in the previously mentioned district Raya Azebo. Third, there has been a global shortage of an effective treatment for malaria and most of the drugs in use had become resistant. Finally, whenever these drugs are available, they may not be used for pregnant women, one of the most vulnerable groups of the population. In addition, impregnated Bed Nets and the new drugs were very expensive.

With continues revision of the 5 year strategic plans in the TMOH bureau , in 2008 the head of the Tigray health bureau Dr. Barnabas in his written message on the 2008 regional health profile report announced that " Some evidences suggest that malaria morbidity and mortality decreased by 50%. And Malaria is no longer the number one killer in the health facilities in Tigray. It has been replaced by AIDS". (TMOH Annual report, 2000). This has been done mostly by increasing bed net coverage and use of indoor spraying. According to TMOH report (2009) the region is expecting to reach the millennium development goal (MDG 6) for malaria on time or even ahead of time.

2.6 Geographic Information Systems (GIS) in Ethiopia

The Geographic Information Systems (GIS) has gained tremendous popularity in Ethiopia by attracting a great number of governmental institutions, the private sector, institutions of learning and non-governmental organizations. Currently , several ministries and departments of the Federal and Regional Governments have initiated the application of GIS for different purposes such as agriculture studies, cadastral mapping, transportation infrastructure, for urban land administration, for land use studies and planning, for transport , for health coverage and disease control, for education and for a variety of other fields and disciplines . The institutional infrastructures have been developed across the country catering to the local, regional and national needs.

The Federal Ministry of Health has a policy which recommends the application of GIS in the health sector in Ethiopia and it recommends that GIS is a powerful visual tool available for planning and monitoring of health services. Even Ethiopia was among the first countries to implement the WHO HealthMapper software at both national and district level . According WHO report (2002) , in Ethiopia the HealthMapper system has been in use at national level as a common platform for the surveillance and monitoring of multiple diseases including malaria, polio, tuberculosis and HIV/AIDS.

Some of the research areas that have used GIS application in Ethiopia includes, 1)A study to develop malaria early warning system (senay&verdin,2005), 2)To support community health workers in malaria controlling program (Ghebreyesus,1999), 3)a research study to develop prediction models for onchocerciasis control (Gebre-Micahel et al, 2005), 4) to optimize trachoma control using GIS mapping (Keuo et al,2006), 5)To explore the existence of oil and gas in Ethiopia by Malaysia oil company ,PETRONAS(Lalef,2008), 6) to locate the best location to vaccine rabies for dogs and wolves in Ethiopia by wolf conservation program and university of oxford (Gordon et al,2010) and a research on application of GIS for forest management.

Despite the noteworthy achievements in GIS and its popularity in Ethiopia, there are still limiting factors that need to be addressed. Among the many, some of the limiting factors are, 1) lack of accurate spatial information 2) lack of nationwide control points for spatial data standardization and quality, 3) Lack of central data warehouse to which people could have access,5) lack of cooperation among professionals , 6) shortage of skilled man power and 7) absence of more convenient repository and retrieval systems (GISSE website &Zeleke et al.,2007).

Recognizing the immense potential of GIS coupled with the existing disparities in its adoption, there is a growing sense among GIS professionals in the country to change the existing situation and confront the major challenges that exist in application of GIS in the country. One example of this is the inauguration of 'Geographic Information Systems society of Ethiopia (GISSE)' which was officially inaugurated in October 25,2007. GISSE is a society of GIS and remote sensing professionals and others interested in the promotion and use of GIS and remote sensing. One of the main aims of GISSE is to promote National Spatial Data Infrastructure (NSDI) in Ethiopia by setting up a national level GIS infrastructure, standardisation, and providing professional assistance by establishing a network of GIS professionals in the country (Zeleke etal,2007).

Currently the country's largest and best organised geo-spatial data provider is EthioGIS database. These data have been compiled by the Soil Conservation Research Project of the Ministry of Agriculture and the Centre for Development and Environment of the University of Bern, Switzerland. The data have been available since 1999 and are being widely used by many people in Ethiopia. The source of the database is topographic maps from the Ethiopian Mapping Agency, soil data from Food and Agriculture Organization (FAO), population data from the Central Statistical Agency, and official administrative boundaries based on the 1994 population census data. This database, however, has limitations for detailed studies at local level (Zeleke et al., 2007). Of course various organisations that use GIS in the country today produce and some also disseminate their own data. For example, the Ethiopian Mapping Agency produces aerial photographs, topographic maps and other derivative geo-spatial data and makes them available to users at reasonable prices. Most of these data are often obtained in paper (analog) format and many universities and research institutions in Ethiopia have also compiled a considerable amount of geospatial data and satellite images of the entire country. These data are often used by researchers and students for different projects. This has the side effect of creating redundant and inconsistent data (Zeleke et al,2007, GISSE website & EMA website).

3. Literature Review

This chapter contains related literatures used in this study. The literature is about geographic information system, geographic information system applied to public health with emphasis on the application of it in malaria field and the principles of cartography in designing and constructing useful and effective maps.

3.1 Geographic Information Systems

Geographic information systems are in general seen by many as a special cases of information systems. For example (Dueker 1979:106) define GIS as "a special case of information systems where the database consists of observation on spatially distributed features ,activities, or events , which are definable in space as points, lines, or areas. A GIS manipulates data about those points, lines, and areas to retrieve data for adhoc queries and analyses". It has also been define as "an information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially referenced data, as well as a set of operations for working /analysis with the data" (Star and Estes 1990). But what is common to All GIS definitions is that all recognized spatial data are unique because their records are linked to a geographic map (space matters).

The component parts of GIS include a database (attributes) and also spatial or map information and some mechanism to link them together. GIS has also been described as the technology side of a new discipline called geographic information science (Goodchild 1990), which is defined as "a research on the generic issues that surround the use of GIS technology, impede its successful implementation, or emerge from an understanding of its potential capabilities".

GIS has emerged as a very powerful tool in the management of spatial information and has become a topic of intense interest for many academic disciplines, government organizations, as well as commercial enterprises. Although GIS has existed since the 1960s (Delaney 1999), its applications have grown phenomenally during the last two decades. The development of cheap and powerful personal computers and user friendly, readily available GIS software has increased the use of GIS technologies in almost every field (Berry 1994; Chrisman 1997; Waller and Gotway,2004; Maheswaran and Craglia ,2004; Burrough and McDonnell 1998). Longley et al (2005) reports that GIS is a highly dynamic field, growing as the same very rapid pace as the change in information technology. Sound understanding of the capabilities of GIS by users, managers, and decision makers is crucial to the appropriate and effective use of the technology.

It is not possible within the space of this thesis to discuss the theory and practice of GIS in detail, so interested readers are referred to some especially useful background texts on GIS, such as Aronoff (1989), Burrough and McDonnell (1998), Chang (200), Chrisman (2002), Davis (2001), Longley *et al.* (2005), Lo and Yeung (2002) and Mitchell (1999), Steinbergn(2006), Cromley at al. (2002).

3.1.1 GIS Definitions

Various definitions of GIS have evolved in different areas and disciplines (Longley 2005) so it is difficult to select one definition that suits all the purposes and concepts of GIS applicable to this thesis. Some main definitions from the literature are shown in Box 2-1:
From the definitions in Box 2-1, some people see GIS as a toolbox that has a number of different roles and capabilities, while others view GIS as a decision-support system for policy making, planning and management (Dent 1999; Maguire *et al.* 1991). The following definition was developed by consensus among 30 GIS specialists from various disciplines (Chrisman 2002): *"GIS is a system of hardware, software, data, people, organization, and institutional arrangement for collecting, storing, analysing, and disseminating information above areas of the earth."*

Box 3-1: Some definitions of Geographic Information System (GIS)

Definition 1: GIS as a toolbox

"a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes" (Burrough 1986).

Definition 2: GIS as a System

"Automatied systems for capture, storage, retrieval, analysis, and display of spatial data"(Cliffs,1995).

"A decision support system involving the integration of spatially referenced data in problem solving environment" (Cowen ,1988).

3.2 Applications of Geographic information Systems in public Health

Public health is defined as "the science and art of preventing disease, prolonging life, and promoting health through the organized efforts of society" (Waller and Gotway 2004). With it's primarily concern as the health of the entire population than the health of individuals (Chrisman 2002).

The field of public health is highly varied and encompasses many academic disciplines, some of them are, environmental health, epidemiology and health service Administration/management. As health is largely determined by environmental factors such as socio cultural and physical environment which vary in space (Tanser and Le Sueur 2002), the spatial modelling capability of GIS is directly applicable to understand the spatial variation of the disease, and its relationship to environment factors and health care systems.

GIS can support public health in different ways; It helps in determining geographic distribution and variation of disease, in monitoring disease and intervention over time, in accessing the need of health care and resource allocation, in accessing accessibility to primarily health care , in determine environmental factors of disease and many more (Johnson and Johnson 2001).

For example, for the Hlabisa health district, in South Africa, an investigation using GIS demonstrated that there exists a substantial spatial heterogeneity of HIV prevalence among pregnant women and that this heterogeneity closely correlates with the distance of the women's homestead to primary and secondary roads .This result clearly pointed to the importance of social contacts with road related populations for women's HIV incidences (Tanser et al 2003).

Alternatively GIS techniques have been used to show a lack of correlation between cause and effect or different effects. For example, the distribution of both birth defects and infant mortality in lowa, USA were studied, and the researchers found no relationship in those data (Rushton G. et al, 1996). This led to the conclusion that birth defects and infant mortality are likely unrelated, and are likely due to different causes and risk factors. In central America in area of Guatemala GIS is being used to identify locations of high prevalence and monitor intervention and control programs for onchocerciasis (Richards 1993). Spatial and ecologic data are combined with epidemiologic data to enable analysis of variables that play important roles in disease transmission. This integration of data is essential for health policy planning, decision making, and ongoing surveillance efforts.

3.3 Application of Geographic Information Systems in Malaria

Geographic information systems (GIS) are a tool of great inherent potential for health as health is largely determined by environment factors including the socio cultural and physical environment (Tanser and Le Sueur 2002). Which makes GIS a powerful tool for malaria control analysis and management since, distribution of malaria is largely determined by climatic factors (particularly rainfall, temperature, relative humidity) and transmitted by mosquito which is constrained only by the flight distance of the mosquitoes (*ibid*).

Sweeney (1998) discuses the contributions which GIS can make to malaria control programs namely: (1**) As operational planning aid** which means the GIS database can be used as operational tools to support planning and implementation of control activities. For example a district malaria control maps with the position of villages in relation to roads, rivers, water bodies and other topographical features can provide an important overview in order resources (manpower, Vehicles and drugs) to be allocated most efficiently and to get the job done easily. (2**) As monitoring and evaluation tool** in a way that GIS resources can also provide a powerful analytical tools in order to establish and confirm spatial relationships among data sets which are epidemiologically significant and the computing power of the relational database in GIS can be applied to investigate the correlations between those data sets while maintaining the spatial relationships between them. This can assist with the identification of problem areas as a starting point in geographic occurrence of malaria cases and helps for further analysis to identify the possible reasons for the higher incidence of malaria in specific places. At the end this approach can therefore be of direct benefit to the evaluation of malaria control programs. (3) **As a research approach.** For example GIS can be used to investigate the association between environmental variables (Climatic factors) and the distribution of the different species responsible for malaria transmission**.**

In recent studies GIS has been Widely applied to the understanding and management of malaria in Africa (Tanser and Le Sueur 2002), such as to generate modes of malaria occurrence, seasonality and transmission intensity using climatic and remotely sensed data; to measure the effects of access to malaria treatment and to evaluate the effects of intervention strategies. For example: GIS was used to develop an atlas of malaria in Africa which contains relevant information for rational and targeted implementations of malaria control by a non-institutional project called MARA/ARMA. In south Africa a GIS-based malaria information system (MIS) was develop and implemented for three malarious provinces (Martin et al. 2002). The MIS system includes automated mapping capability using MapInfo and a relational database using Microsoft access. It also contains data about imported malaria incidences, Locations of schools, Health facilities and location of homesteads.

GIS has also been actively used in other parts of the World . For example GIS was used in designing a national surveillance system for the monitoring and control of malaria in Israel (Kitron et al. 1994). The system included data on the locations of breeding sites of Anopheles mosquitoes, imported malaria cases, and population centers. The GIS-based surveillance system used to calculate distance between population centers and breeding sites, and maps containing information about epidemiological and entomological data were produced. In southern area of Chiapas, Mexico GIS were used to identify villages at high risk for malaria transmission using remote sensing based models (Beck et al. 1997).

3.4 Principles of Cartography: *Communicating Information through Maps*

The process of mapping falls into four categories as it shows in figure 3.1 below: Planning, analysis, presentation, and production /reproduction In the planning phase, the map maker must have a clear idea of the purpose and topic of the map, where it will be presented, and for whom it is designed. This will govern the type of data collected. Analysis phase involves collecting, synthesizing, and analyzing the data. The data are analyzed and symbolized using statically tools, in this thesis we use ArcGIS 9.3 and Microsoft excel software to analysis our data .For presentation, the elements of title, legend, scale, orientation, text, and illustrations are organized into a layout. At this stage the map maker must know where and how the map will be viewed or produced. After the map is created, but before production / reproduction, one should critique and edit the map based on questions like do the symbols, color, and line work? Finally the map will be ready to be published .

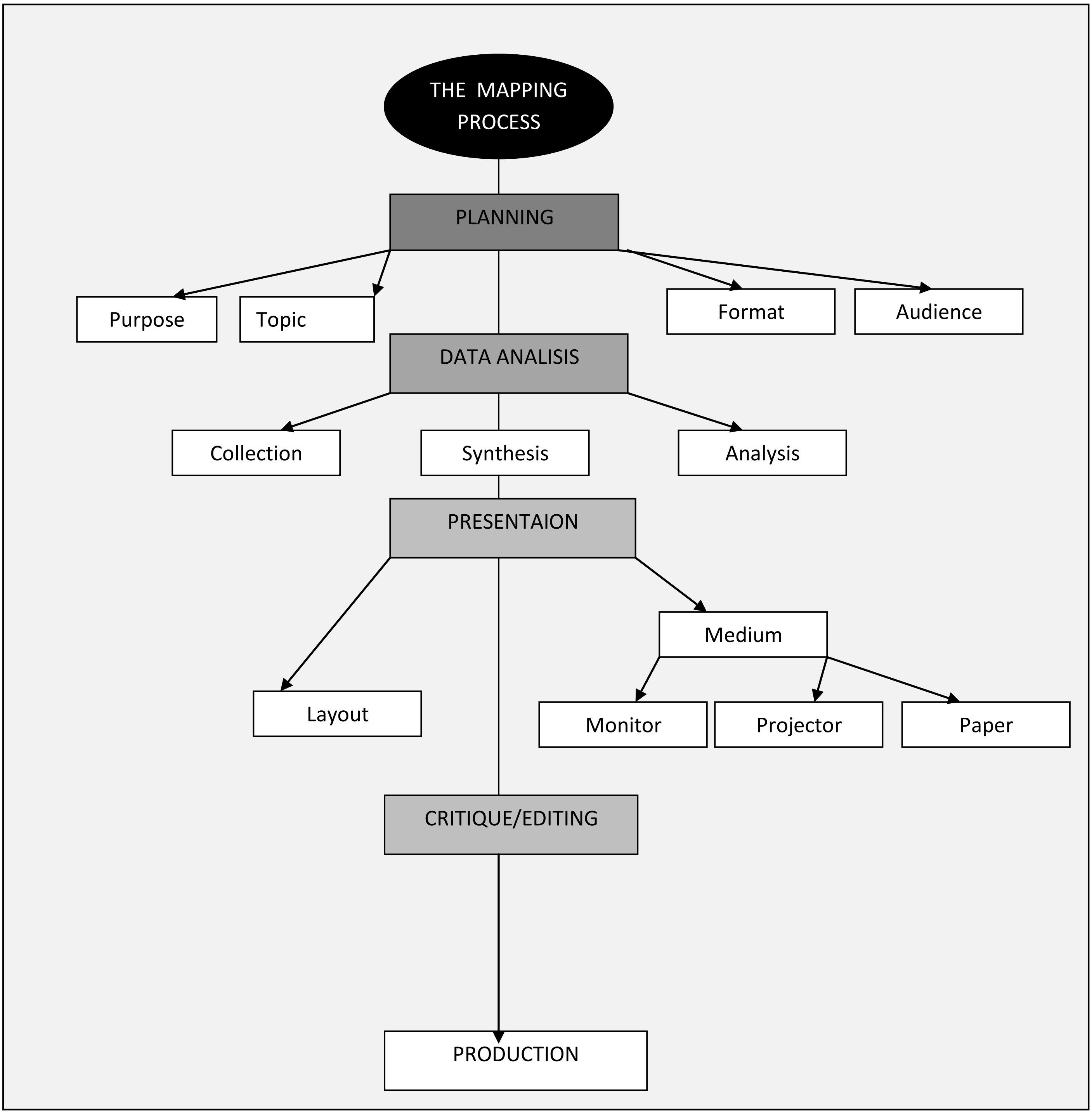

Figure 3.1 The mapping process (Tyner 2010)

The basic steps for communicating map information were taught with in the frame work of map communication models more or less similar to the mapping process model in figure 3.1 (e.g. Dent (1999) and Slocum et al. (2009)).

According to Slocum et al. (2009) "though such models have received criticism (e.g., MacEachren 1995, 3-11), their use often lead to better designed maps". For this thesis, I adopt the map communication model (see figure 3.2) described by Slocum et al. (2009). It contains a set of five idealized steps.

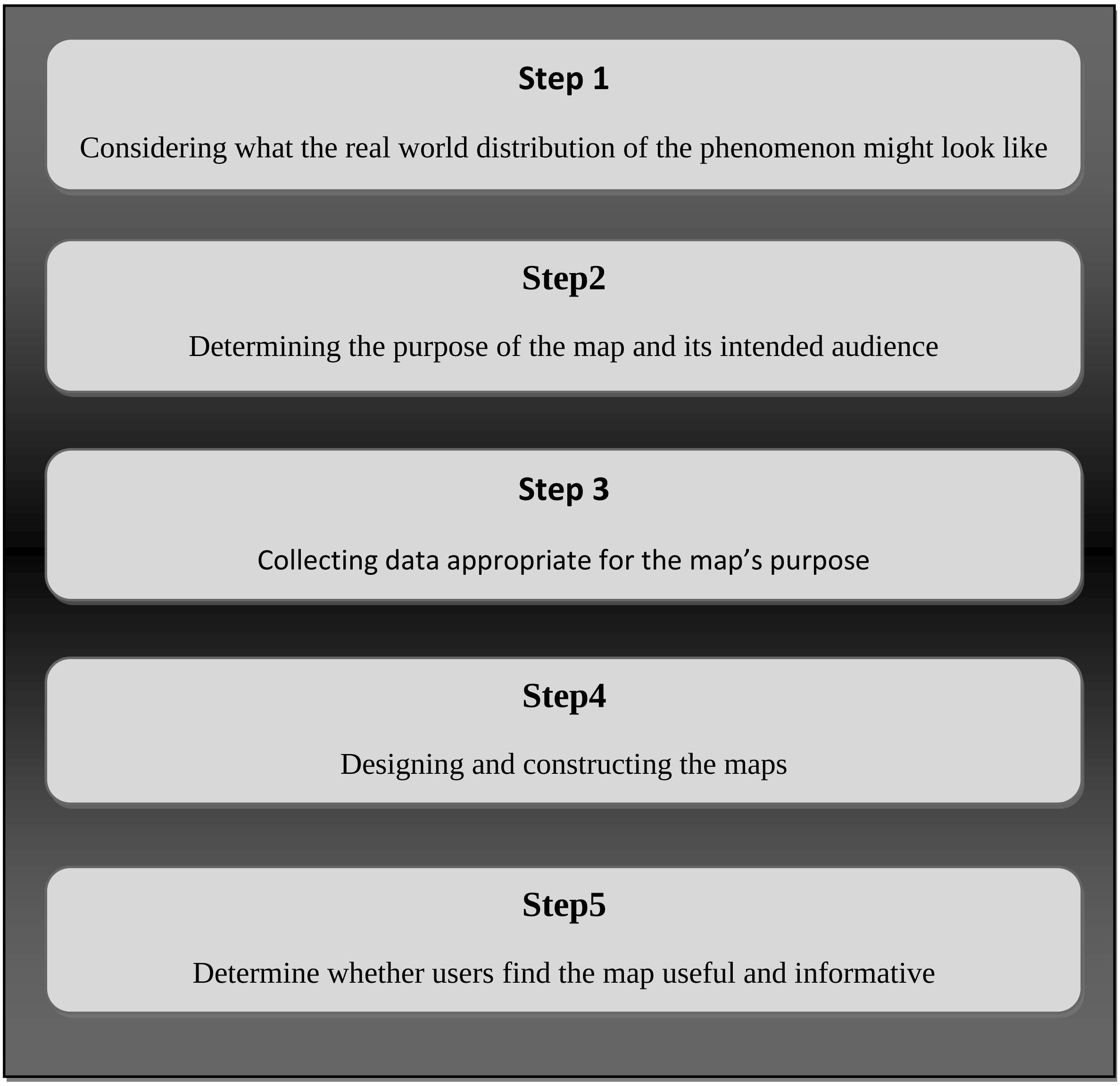

Figure 3.2 Basic steps for communicating map information to others (Slocum et al. 2009)

3.4.1 Considering what the real world distribution of the phenomenon might look like.

According to Slocum et al. one way to implement this step can be to ask our self's "what would the distribution of the phenomenon would look like if we were to view it while traveling across the landscape?". If we take population distribution as an example, we might know (based on our previous knowledge) that a large percentage of the people are concentrated in major cities and such cities are much more densely populated than the rural areas. If we take distribution of malaria situation, based on the information from chapter one malaria transmissions depends on latitude and rainfall. Transmission usually occurs at latitudes below 2000 meters and in areas with high temperature .This can give us general impressions of which areas are most and least malarious.

Often, however, it is unrealistic to assume a single objective of a real world because of different problems. For example in the case of population distribution, census figures do not necessarily count the homeless people. In spite of those problems it is useful to think of the real world distribution of the area. Such an approach forces us to think about the distribution at its most detailed level, and then help us to decide the scale of our map.

3.4.2 Determining the purpose of the map and its intended audience.

Simply writing out the purpose of the map prior to making it will clarify goals, help us determine relevant data, map design and symbolization choices and will lead to a better map (Krygier and Wood 2005). In effect the purpose(goal) of the map asks question what the reader should gain from the map or how the reader should respond (Robinson, H. et al. 1995). Health maps has been developed with different purpose including to identify population at risk, to assess health care coverage , to highlight the geographic spread of disease, to assessing resource allocation, and to support monitoring and analysis of trend (O'Neill and Meert 2007). An example of Maps designed with the purpose of assessing health care coverage which are also called service availability maps in (*ibid*) provides health planners with a detailed picture that can be used to show where health services are adequate, where they are thin on the ground or nonexistent , and where they are heavily concentrated. This information is critical in efforts to strengthen health service delivery systems, in planning disease control programs, and in efforts to ensure that essential health services are equally accessible to all people including those who are difficult to reach. Box 3.2 contains some examples of maps which are designed for different purpose.

Box 3.2 List of maps designed with different purpose

Example of service availability (health care coverage) maps

-A map showing number of doctors per 10,000 people in Zambia 2004.

-Map showing location of antiretroviral therapy (ARV) sites in Zambia, 2004

-Map showing location of sites providing tuberculosis (TB) diagnosis (*ibid*)

Example in maps designed with the purpose of showing trend

-Maps showing the trend of HIV infection over a period of 10 years in Nepal (Suvedi 1999).

Monitoring progress towards dracuncluliasis eradication in Burkina Faso, 2000-2003 in (O'Neill and Meert 2007).

Example of maps produce with the purpose of highlighting the distribution of geographic spread of disease

*A map showing distribution of malaria in africa (MARA 1998)

*A map showing confirmed malaria cases in Ruwanda, 2003 (O'Neill and Meert 2007)).

The nature of the intended audience also plays an important role in designing a map. As it is explained in (Krygier and Wood 2005). **Experts** on the subject of the map know a lot about the subject, so they are highly motivated and very interested in the facts the map represent. They expect more substance and expect to engage a complex map. With More information, more variables of information and more detailed. According to john and Wood It is also recommended to **follow** conventions of experts like consider using a spectral (rainbow) color scheme for ordered data. If the user is not accustomed to using such colors Spectral color schemes are not usually good for other users. People who are new to the map subject (novices) knows less and may not be familiar with the way maps are symbolized. They need a map that is more explanatory. They may be less motivated than expert users, but they want the map to help them learn something. They expect clarity, and may be put off by complex map. For instance the general public needs to know about malaria condition on their local area, but they are not trained malaria experts. They need a map designed for them with less information, fewer variables of information and less detail.

3.4.3 Collect data, appropriate for the map's purpose

Spatial data can be collected from primary sources (e.g., field studies) or secondary sources (e.g., Census data). In our case we use secondary data from three different sources. For more detailed please refer chapter 3(data and methodology).

3.4.4 Designing and constructing the map

Designing and constructing the map involves selecting an appropriate symbology (e.g. using a dot map rather than a choropleth map) and also selecting and positioning the various map elements (e.g. title, legend, and source). So that the resulting map will be both informative and visually pleasing (Dent 1999; Slocum 2009; Tyner 2010; Robinson, H. et al. 1995). According to Slocum et al. (2009), this step is a complex one that involves assessing questions about the data type, the type of the map , the nature of the intended audience, the constraints of time and money , technical limitations and the number of attribute variables to be mapped . Box 2-3 contains some of the questions that needed to be assessed in this step.

Box 3-3: Some of the questions that needed to be assessed in designing and constructing a map

- ✓ How will the map be used? Will it be used to portray general or specific information?
- ✓ What is the spatial dimension of the data? For instance, are the data available at points, do they extend along lines, or are they areal in nature?
- ✓ At what level are the data measured –nominal, ordinal, interval, or ratio?
- ✓ Is data standardization necessary? If the data are raw totals, do they need to be adjusted?
- ✓ How many attributes are to be mapped?
- ✓ What are the characteristics of the intended audience? Is the map intended for general public or for professionals?
- ✓ What are the time and monetary constraints?

Source: Slocum et al. 1999.

3.4.4.1 Choosing Projections and coordinate systems

We make maps for a particular reasons, and those reasons guide the selection of a particular map projection (which gets us flat) , an appropriate scale(how much of the earth to show and at what size) , and a coordinate system (which help us locate things on the map. Our earth's surface is curved and most maps are flat. Transforming the curved surface to a flat surface is called map projection. Projection matters because of what they do to our data (Krygier and Wood 2005).

Mappable data is always associated with a location on the earth's surface. That is mappable data is always tied to the grid , and this grid gets distorted when it's projected from the curved surface of the earth to the flat surface of the map. The data tied to the grid gets distorted too. But no map projection preserves all the attribute of a globe, which maintains area, shape, distance, and direction. Map projection can only preserve one or two of the attributes of the globe, but not all, so it is important to select a map projection that makes the best sense for our data (Dent 1999). We have to be smart with selecting projections and understand the tradeoffs (Krygier and Wood 2005). For example, in the case of areal data, it is better of choosing projection which distorts shapes and preserving areas.

3.4.4.2 Choosing Map scale

All maps are drawn to a scale, which means they are drawn smaller than reality and this makes maps useful (Tyner 2010). Technically map scale is defined as a ratio of map distance to earth distance (e.g., 1:250,000), with each distance expressed in the same unity appears in the numerator (Dent 1999).

Several factors impact on choosing a scale for a map: the subject and purpose of a map, data resolution, map user needs, and the specified format. For instance, if a map is designed for navigation or hiking or bicycling, it will need to contain more detail information than if it is designed to show an overview of a water body than a national park or a recreation area .The resolution or detail of the data represented also is of importance in choosing a map scale. If a great deal of detailed must be represented, then the scale ideally will be larger than if the data resolution is less (Tyner 2010). At times the page format is specified and the map must fit within its confines. If the area is large , then the map maker has few options other than including larger scale insets to show the details of some areas . For example the scale of a map will be different for paper maps, Newspaper maps ,screen maps and TV maps (Slocum 2009).

3.4.4.3 Choosing Map Coordinate system

Map coordinates are a pair of numbers or letters which locate a point on a map. Linear features, such as rivers, are located as a string of connected point coordinates. Area features, such as a country, are located as a closed string of connected point coordinates. There are many different map coordinate systems with different origins. When two or more digital maps are combined (as layers in GIS) they must have the same coordinate system, or they will not align properly. New created data using GPS or digitizing should also be in the same coordinate system as the other digital maps which are to be used with. Coordinate systems have different units of measurements. They can be in English units (feet), metric units (meters), or degrees.

3.4.4.4 Choosing appropriate data classification and symbolization methods.

“Everything on a map is a symbol“ (Krygier and Wood 2005). The selection and design of a symbol is a major part of creating a successful map. Because of this the map maker must choose symbols that are distinct and easily identified in the legend and must also choose the symbol system that most effectively portrays the relationships featured (Tyner 2010). Some of the basic map symbolization issues listed by (Krygier and Wood 2005) are:

a. *Identifying the kinds of data:* This asks questions like is our data at points, a long lines, or over an area? Is our data qualitative or quantitative ? Do we have individual data values or aggregated (grouped)?

b. *Choosing the visual variable (map symbols):* Particular visual variables intuitively suggest important characteristics of the data. Eight kinds of visual variables are accepted by almost all cartographers (Tyner 2010), namely, form, size, hue, color values or lightness, color intensity or (saturation), pattern, texture, and orientation.

c. *Symbolizing aggregated data*: choosing thematic map design techniques

Symbolizing data along points, lines and areas

Two kinds of data are symbolized at points: those that actually occur at points, such as location of places, and data that are aggregated at a point, such as totals for countries or other enumeration area. Both qualitative and quantitative data may be shown by point symbols as pictorial, associative, or geometric. But most often qualitative point data symbolize by shape and hue and Quantitative point symbols by size and location (dot map) (*ibid*).

Data along lines can also be qualitative or quantitative like the point data. Qualitative line data are usually symbolized with hue, form, pattern, and orientation. A common example is a transportation map that uses different hues for roads, railroads and rivers. Quantitative line data that is like if the data is in order or ranked categories different in size, width, hue or lightness symbol is used. (*ibid*).

In representing qualitative areal data the symbol (visual) variables employed should be hue, pattern, and orientation. Different hues represent different vegetation type or land use categories. The main concern here is that there should be logic to the choice of hues or color used. (*ibid*).

Some rules in selecting visual variables for the data

Map symbolization is a complex process. Visual variables can guide on basic map symbolization decisions, but they cannot solve all map symbolization issues. (Krygier and Wood 2005). Particular visual variables intuitively suggest important characteristics of the data. Krygier and Wood (2005) put some basic guides on choosing the visual variables related with the data type.

The general rule is that if the data is qualitative then choose a visual variable which suggests qualitative difference (shape, color hue) and if the data is quantitative choose a visual variable which suggests quantitative differences (size, color value).

According to Krygier and Wood (2005) visual variables can be of three types:

(1) **Symbols by relationship**: Those symbols intuitively suggest general kind of data. For example a map with symbols of different shapes and color hue shows different in kind .A map symbolized with different in size and color value implies different in quantity or rank. Some other visual variable can also be used to show both qualitative and quantitative difference or to represent data which are difficult to categorize. E.g. Color intensity (saturation) visual variable is best used to show subtle data variations. Such as yes/no data that are difficult to categorize as qualitative or quantitative. And symbols which are

represented as texture (pattern) difference can be used to show both qualitative (bricks vs. cloth) and quantitative (coarse vs. fine) differences.

(2**) Symbols by resemblance:** Symbols which look like particular data or concept. E.g. A map showing a location of airports uses an airplane symbol and maps in war areas show red symbols to show the location of the battles.

(3) **Symbols by convention**: Those symbols make sense even though they may not entirely make sense. E.g. blue for water body, green for forest

Symbolizing aggregated data - choosing thematic mapping techniques

Symbolizing data that have been grouped into geographic areas (countries, districts etc.) is complicated, since it is possible to produce different kind of maps using the same data. Selecting the appropriate mapping technique for the aggregated data requires both understanding what is going to be mapped and the goal of the map (Dent 1999; Krygier and Wood 2005; Slocum 2009).

The four common thematic mapping techniques are : 1) Choropleth mapping 2) Graduated symbol maps 3) Dot maps and 4) Isopleths maps

Choropleth mapping techniques:

Choropleth mapping has also been called area or shaded mapping or enumeration mapping (Dent 1999). It is constructed when data occur or can be attributed to definite enumeration units- state, province, countries etc. It is not acceptable to map total values when using the choropleth technique (Dent 1999; Krygier and Wood 2005). The reason for this is in most choropleth mapping situations, the enumeration units are unequaled in area. The varying size of areas and their mapped values will alter the impression of the distribution. If the data cannot be dealt with as ratio or proportions or standardize in some way, then they should not be portrayed by choropleth mapping technique (Dent 1999).

Graduated symbol mapping techniques

The graduate symbol map varies the size of a single symbol, placed within each geography area, following with the data value associated with the area (Krygier and Wood 2005). As it is explained in (Dent 1999) there are two commonly accepted instances when graduate point mapping is selected by map makers. Those are when data occur at points and when they are aggregated at points within areas. According to dent practically any magnitude can be symbolized using this technique: totals, ratio, and proportion. But the graduate symbol form of mapping techniques is most appropriate whenever the goal of the map is to show the relative magnitude of the phenomena at specific locations. Mapping a derived data (density, rate, etc) with a graduate symbol map is often not recommended, because graduate symbols readily imply magnitude rather than density or rates (Krygier and Wood 2005: 214). In choice of the visual variables, circle, square, and triangles are the most common forms used in proportional symbol, with circle being the dominant form. This is because circles are more compact and more visually stable than any other symbol (Dent 1999: 175). According to dent even though it is possible to use two proportional symbols to illustrate two distributions on the same map, it is discouraged because it introduces to much complexity to the map and can undermine the communicative effort of the map. A better solution would be to develop two separate maps.

Dot mapping techniques

The dot map varies the number of dots in each geographic area, based on the single data value associated with the area . Its main purpose is to communicate variation in spatial density (Dent 1999). Dots on a dot map do not represent the specific location of a single instance of some phenomena; rather the density of dots in a geography area represents the density of phenomena in that area. In most basic form, dot maps use a single dot (“dots “ may actually be circle, square, triangles, or other shape) to represent a given quantity, such as one dot represents one house , or one dot represent 500 people (Tyler 2010).

The appropriate data to be mapped using dot maps is totals. Using a dot map for derived data (standardized data) is not recommended. ”one dot equals 50 people per square miles is too weird to think about “ (Krygier and Wood,2005:220) .

Isoplethic mapping techniques

Isoplethic maps (surface maps) create an abstract 3D surface based on one data value associated with each area .Surface maps can also be created from data at points (isometric maps) . Isoplethic mapping should be selected only if the advantages of its use contribute to achieving the goal of the mapping task and the map data should be in the form of a geographic volume and continuous in nature (Dent 1999: 193). The appropriate data for isoplethic map is derived data (densities, rates). Like choropleths maps using total data for

Isoplethic maps is not recommended, particularly when the area in the map vary in size. A large area may have look more people simply because it covers a large area (Krygier and Wood,2005).

There is no absolute best kind of data for any of the above techniques. The main message on the above appropriate data suggestions for these techniques are to make us aware of the problems with using the different data. If our goal for the map that we design require us to use the unrecompensed data types, then we just have to do it and create another map with another mapping techniques using the same data and compare the maps (Dent 1999; Tyner 2010; Krygier and Wood,2005).

Data Classification techniques

Data values are grouped into classes to simplify mapped patterns for the reader and for better management of symbol selection and map readability. In practice not more than six classes are recommended (Dent 1999).

There is no one best way of devising class intervals and class boundaries for any maps. The major goal is simplicity and also the class interval systems should include the full range of the data, have no overlapping classes and reflects some logical division of the data array in order to portray the purpose of the map (Slocum et al. 2009). There are several class-interval methods, but the ones we used on classifying our data for the maps we produce for this thesis are: Natural break, equal interval and quantile .

Natural break method

The natural break(Jenks) method is a widely accepted method and it has the logic which is very most consistent with the purpose of data classification that is forming groups that are internally homogeneous while assuring heterogeneity among classes (Dent 1999).

Quantiles

In quantiles method of data classification, data are rank ordered and equal numbers of observation are placed in each class. An advantage for this method is that because an equal number of observation fall in each class, the percentage of observation in each class will also be the same and it is useful for ordinal data because its class assignment is based on rank order (Slocum et al 2009:59). Its disadvantage is the result of a gap in data value because the reader might wonder why they occur, however the gaps do also permit the legend to reflect the range of data actually occurring in each class.

Equal Interval

In equal interval method of classification, each class occupies an equal interval along the number line. The advantage of this method is in some cases, it is easy for map readers to interpret and also the legend limits no missing value or gaps.

Selecting and positioning map elements

Map elements represent the building black of map communication which is the transmission of geographic information through the use of maps (Slocum et al. 2009). The most common map elements are a title, legend, scale, explanatory text, directional indicator, source and credits, a frame line/neat line, and an inset / locator maps (Krygier and Wood 2005). These map pieces are systematically arranged around and upon the map. Below we have some useful advices on how to use map elements effectively from (Krygier and Wood 2005: 128-137) which we used in our map design.

Frame line and neat line

The frame line and neat line help to organize the maps contents and to define its extent. A frame line encloses all other map elements; it is similar to a picture frame because it focuses the map users' attention on everything within it. The style of the frame line should be subtle. A single thin, black line should be used (Slocum et al. 2009). It should be noticeable but shouldn't be too noticeable (Krygier and Wood 2005).

Insets and locator maps

An inset is a smaller map included within the context of a larger map. Insets are useful to show the primary mapped area in relation to a larger, more recognizable area. If the legend has different symbols from the main map it is good practice to include an inset legend and an inset indicator for the inset (*ibid*).

Title

Map title varies greatly, but should attempt to include the topic of the map, the geographic area and temporal information about the data. Since titles are important elements of the map, the type size of the title should be two or three times the size of the type on all the elements of the map. A subtitle in smaller type is also appropriate for longer titles or more complex map subjects (*ibid*).

Legend

Map legends vary greatly, but should include any map symbol you think may not be familiar to your audience .Legend is the key to interpreting the map. If it fails, the goal for the map fails. However, be careful not to insult your map readers by including obvious symbols in the legend (Krygier and Wood 2005). E.g. no need to preface the legend with “legend” or “key” since most map readers know that without being told .

Scale

Most large and medium scale maps should include a scale indicator, particularly if your map reader need to make measurements on the map .If your map users might reduce or increase the size of the map, the visual scale is the best option, since it will remain accurate even if scaled.

Verbal scale : 1 inch =2500 miles visual scale = 0----------3000mi Numerical scale 1:22,000,000

Directional indicator (usually north arrows)

A directional indicator is needed on a map for two main reasons: When the map is not oriented north and when the map is of an area unfamiliar to the intended audience. It is always advisable to avoid large and complex directional indicators since they are relatively unimportant map elements, and should not be visually prominent.

Sources, Credits

Each map we make should include information about data source, map maker and date of production, map information and coordinate system information.

Arranging map layout

“Reading a map is like reading a page in a book: You start in the upper left and end in the lower right” (Krygier and Wood 2005: 200). Most map readers scan the entire map in this manner prior to a more careful reading of the map. So it is best to position those map elements that should be seen first in the upper left part of the map (ibid).

3.4.5 Determining whether the user find the map useful and informative

"It is good to Change the design of your map if you are not satisfied with anything" (Tyler 2010). But the most important question to ask when you evaluate our map is , such as does the map do what I want it to do? is the map suitable for the intended audience ? Will it be confusing ,boring ,interesterestering , or informative ? (Krygier and Wood,2005). But ideally we should get feedback about the our maps from potiential users (Slocum et al. 2009).

4. Data and Methods of Analysis

4.1 Introduction

This chapter is divided into seven sections. Section 4.2 provides the software package used for this study, section 4.3 the overall process framework used in this study, section 4.4 will provide a brief overview on main literatures used on this study and section 4.5 is reserved for the general GIS analysis done on this study staring from identifying the problem to constructing the maps. Section 4.5 is based on the GIS analysis model shown in figure 4.2 from ESRI and it includes processes on identifying the problem, identifying the required data and collecting the data, planning and preparing data for data analysis and executing the analysis or constructing the maps.

4.2 GIS software used for this study

The software used to store, analyze and display all of the GIS data for this study was ArcGIS 9.3.1 which is a product of ESRI. ESRI is the world's leading producer of GIS software and ArcGIS 9.3.1 is the latest version of their Desktop GIS package. These products have extensive capabilities however they involve steep learning curves and their cost is very high. The reasons for the selection of this software package for this study are two. The first one is because I was introduces to this software when I was attending GIS course in autumn 2009 and become familiar with it. At the same time, I got a privilege to get the software with one year license from the department of geo-science in Oslo University. This made it easy for me to install and use it on my laptop. The second reason is that, it is widely available at the lab computers on the University of Oslo.

4.3 The methodological framework

The framework outlined in Figure 3-3 shows how the research originated, and how the researcher's capacity was developed. The top row of boxes shows the background of the study, in which the researcher was mainly involved in gathering background knowledge and skill. Later in the process, data collection commenced from various sources for developing the useful maps for malaria management. Data was checked for its quality at the time of collection and later on analysis. After those maps were produced, they were sent to one target group to get feedback on the content of the map and on the design of the map. The feedback of the target group is incorporated on the final design of the maps.

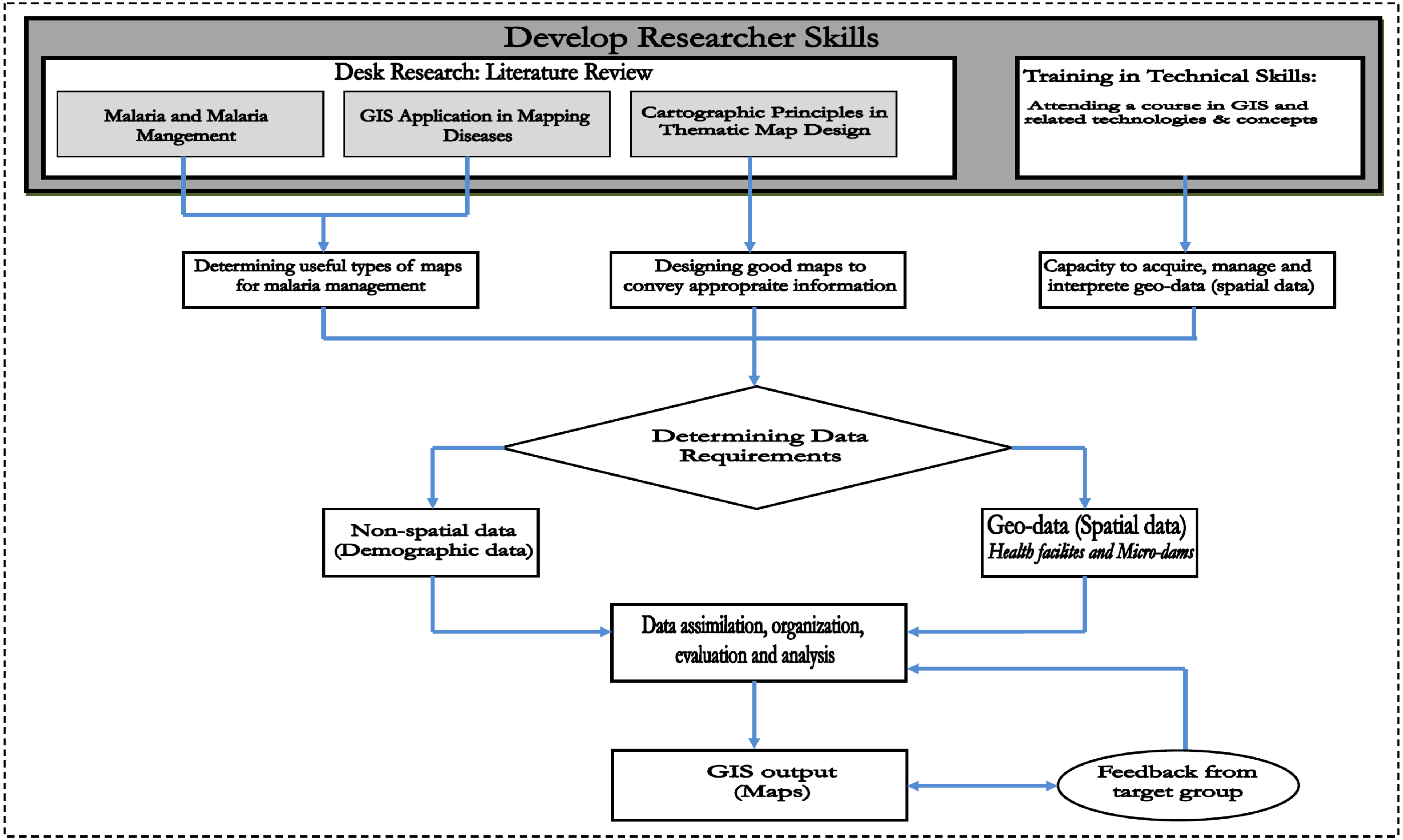

Figure 4.1: Research Framework

4.4 Theoretical background of the study

The research process started with review of literature on malaria and malaria management programs, on applications of GIS in public health particularly in malaria and its potentials and limitations. The author learned the principles of GIS and related technologies and gained practical experience about GIS software by attending various training courses, courses on the university campus and free online trainings offered by ESRI Inc. In addition to this the author studied the principles of cartography and thematic map designing principles in depth from various known cartographic books. Some of the especially influential text books used in the review for this study includes GIS and Public Health by Cromley & Mclafferty (2002), GIS in Public Health Practice by Maheswaran (2004), applied Spatial statistics for Public Health Data by Waller& Gotway (2004), Thematic Cartography and Geo-visualization by Slocum et al. (2009), and Geographic information Systems and Science by Longley et al. (2005). I addition to those our main source on GIS application were drawn from various scientific journals (e.g. Journal of malaria ,international journal of health geography, Cartography and Geographic information Systems), student thesis, annual reports of WHO, Publications of Tigray regional health bureau, Ethiopia demographic and health survey (2005) and resources from the internet. The review of the literatures and the exclusive concepts used for this study are briefly presented in chapter two.

4.5 Over view of the general GIS analysis

GIS analysis takes a stepwise approach, from defining the problem to examining and displaying the results, as seen in Figure 4.2. The process map displayed in figure 4.2 outlines the method of analysis used in this study.

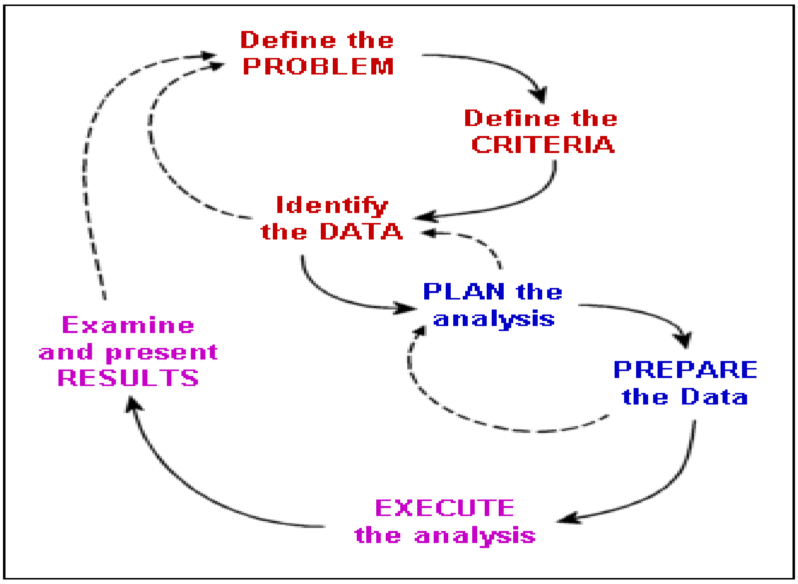

Figure 4.2 Process Map for GIS Analysis

Defining the problem

In this study, the problem is defined as what kind of useful maps can be created for assisting malaria management and how can it be designed effectively and efficiently to give accurate information.

Defining the Criteria

The next step, using the GIS process map as a guide, defined the criteria for this study. Based on the knowledge we gained from the literatures, we come up to know how GIS is applicable in malaria. Based on this , this study includes factors which can help us to analyze the malaria incidence in the region, to identify endemic areas and in need of prevention, to provide information on health care access in the region and to assess the correlation between malaria incidence and potentially related variable (Water body, rainfall, temperature, elevation) . Factors evaluated in this study include all districts which report malaria incidence, all health institutions in the region, dams and rivers. (This study does not include the analysis of rainfall, elevation, temperature analysis in relation to malaria incidence because of data limitation).

4.6 Identifying the data

The next step, based on the process map in figure 4.2, identified the data required for this study. The required data for the analysis consisted of shape files of district boundaries of the region, location of health institutions (hospitals, Health centers, Clinics, Health posts) in the region and for assessing potentially related variables we identify location of dams.

6.4.1 Data sources

Spatial data

The spatial data of the district boundaries, villages and dams of the region was accessed from geology department in Mekelle University in Tigray, where I am a full time academic staff and the location of the health institutions were downloaded from the WHO GeoNetwork database (http://apps.who.int/geonetwork/ in November 2009.

Non spatial data

Information on malaria incidence and demographic information was collected from the tigary heath bureau official website (http://www.trhb.gov.et/pdf/) annual report on regional health profile for the years 2006 to 2008. Similar data for the year 2004 and 2005 was collected from a printed copy of the regions health profile annual report which is published by the ministry of health Tigray in collaboration with WHO.

As it shows in figure 4.4 the tables in the health profile publication of the region contains data for all top ten morbidity and mortality diseases in the region and other health related information. The report presents the malaria cases data as aggregated for different health facilities ,so that malaria cases reported from hospital and health center and cases reported from health post and clinics are in two different tables . Also, the data come and –with different names, being malaria unspecified, malaria PV, and malaria. Since the aim of this study is to show the severity of the malaria incidence in the region, we sum up all the malaria cases in spite of its reported name and for all of the health facilities to get the total malaria patients in each district. A data element with the name ‘ malaria patients ‘ were created in the data collection format that we prepared to hold this data for each and every one of the 35 districts.

In addition to this three excel files were created for data collection. The first one to collect information on patients treated by community health workers with data elements female, male and children under five years. The second spreadsheet contains population information and the third one to collect number of nets distributed from all of the specific districts. Thus, all the non-spatial data was encoded to Microsoft excel program manually.

In an effort to ensure data quality, the non spatial data have been checked for its completeness, correctness and consistency. On our checking for the completeness of the data, we found out that some of the districts do not have data for patients treated by the community health workers on the annual report. However; the data collected for this study has been compared with what has reported on the original source (the annual reports).

The data has also been check for correctness and it was found out that the number of malaria patients on one districts for the year 2004 was reported as higher than the number of population which residence on that district. The data might have been reported wrongly or some patient might have been sick twice in that year and get registered in the system more than once.

Data has been checked for its consistency and it has been found out that for some of the district's the data reported shows large gaps compared with what has reported the immediate previous years. For example for the district called ‘ Ofla’ the number of malaria patients reported for the year 2007 was ‘10597’ and in 2008 it is reported as ‘111’ number of patients. This seems not right.

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Top Ten New Outpatient Cases: Clinic And Health Post

All New Cases			All New Female Cases		
Rank	Diagnosis	Total	Rank	Diagnosis	Total
1	MALARIA	11,089	1	MALARIA	4,169
2	INTESTINAL PARASITES	5,801	2	INTESTINAL PARASITES	1,911
3	DIARRHEA	4,581	3	TB, EXTRA PULMONARY	1,198
4	TB, EXTRA PULMONARY	3,534	4	DIARRHEA	1,185
5	FEVER OF UNKNOWN ORIGIN	3,104	5	FEVER OF UNKNOWN ORIGIN	1,017
6	OTHER DISEASE	2,863	6	ANEMIA	998
7	ANEMIA	2,484	7	OTHER DISEASE	868
8	EYE INFECTION	1,949	8	GASTRITIS, DUODENITIS	604
9	COUGH, INFLUENZA	1,625	9	EYE INFECTION	566
10	GI, OTHER	1,488	10	GI, OTHER	468
	TOTAL TOP 10 CASES	38,518		TOTAL TOP 10 FEMALE CASES	12,984
	TOTAL CASES	46,305		TOTAL FEMALE CASES	15,266

Malaria Treatment by CHWs

CHWs Treat With Fansidar	Total Treated	% Females	% Child < 5
23	24,510	41%	6%

Budget Summary

Type	Allocated	%Spent
Capital	NA	NA
Recurrent	NA	NA
Total		

One way Walking Time To Nearest Health Facility

Time	Estimated Distance	% Pop.
Less than two hour	With in 10 km	44.9
Above Two hours	Above 10 Km	55.1

Pregnancy, Delivery and Neonatal Conditions

Maternal Condition						Neonatal Condition			
Normal Delivery	Caeserean Section	Referral	Postnatal Visits	Abortion	Deaths Due To Pregnancy and Delivery	Total Births	Low Birth Weight (<2.5kg)	Stillbirth	Deaths Within 28 Days
258	2	4	117	16	3	248	13	12	

% Population by Altitude

<1500 Masl	1500-1999 Masl	>2000 Masl
44	10	46

Masl = meter above sea level

Top Ten New Outpatient Cases, Admissions, Deaths: Hospital And Health Center

All New Outpatient Cases			All Admissions			All Deaths		
Rank	Diagnosis	Total	Rank	Diagnosis	Total	Rank	Diagnosis	Total
1	MALARIA, UNSPECIFIED	8,048	1	MALARIA, UNSPECIFIED	740	1	MALARIA, UNSPECIFIED	17
2	HELMINTH, OTHER	2,550	2	NORMAL DELIVERY	128	2	INFECTIOUS, PARASITIC, OT	5
3	INFECTIOUS, PARASITIC, OTHER	2,360	3	MALARIA, PF	90	3	MALARIA, PF	5
4	AURI	1,645	4	INFECTIOUS, PARASITIC, OTHER	86	4	ANEMIA, PERNICIOUS	4
5	SKIN INFECTION	1,235	5	PNEUMONIA, BRONCHO	65	5	GI, OTHER	3
6	RESPIRATORY, OTHER	1,163	6	SKIN INFECTION	57	6	TB, RESPIRATORY	3
7	GASTRITIS, DUODENITIS	805	7	RESPIRATORY, OTHER	45	7	ACCIDENT, OTHER	2
8	MALARIA, PV	712	8	MALARIA, PV	37	8	CIRRHOSIS	2
9	STREP PHARYNGITIS	709	9	ANEMIA, PERNICIOUS	33	9	PREGNANCY, OTHER	2
10	EYE, INFLAMMATORY	705	10	NEPHRITIS, ACUTE	26	10	AIDS	1
	TOTAL TOP 10 CASES	19,932		TOTAL TOP 10 ADMISSIONS	1,307		TOTAL TOP 10 DEATHS	44
	TOTAL OUTPATIENT CASES	29,386		TOTAL ADMISSIONS	1,775		TOTAL DEATHS	54

Population

Years	Male	Female	Total
0-4	10,126	9,769	19,895
5-14	16,036	15,147	31,183
15-44	23,958	24,142	48,100
45-64	5,720	6,232	11,952
65+	2,074	2,087	4,161
Total	57,913	57,379	115,292

Figure 4.3 Tsegeda District annual health profile table, 2004, Tigray

Planning the analysis

The next step involved planning the analysis. The plan for this study was to do analysis that can help us show the malaria incidence distribution in the region, distribution of health facilities and based on the data collect for the location of dams to create maps that can help us access the effect of their existence in malaria incidence. The specific plan for the analysis consists of collecting and preparing the data in various formats in order to create the following eight set of maps. 1) map of malaria incidence rate, 2) Map of malaria anomaly 3) map with distribution of health institutions in relation to population 4) map with distribution of health institution in relation to villages and malaria incidence 5) trend map of malaria incidence in relation to insecticide treated nets for three consecutive years 6) map to show the comparison of malaria incidence for the year 2007 and 2008 7) trend map of malaria incidence and nets distributed in relation to population for the year 2006 to 2008 for the western zone of Tigray and 8) to design a map to access malaria incidence in relation to location of dams .

It is important to distinguish that there are two common models used to represent geographic data: the vector data model and the raster data model. This study used the vector data model. Objects in this study are represented by either a point, line or a polygon feature with well-defined boundaries, as a feature class. A feature class consists of a collection of geographic entities with the same geometry type (such as point, line, or polygon), the same attributes, and the same spatial reference. Points are generally defined by a single x,y coordinate and lines are formed by connecting the points (set of points) , while polygons are defined by lines that close to form polygon boundaries . The location of all the health facilities, villages, dams, are represented as points with x, y value and the district boundaries are represented as polygons with a set of x, y coordinates.

4.6.2 Preparing data for analyses: Preparation of the spatial data for analysis

As we mentioned it earlier the spatial data are collected from different sources. District boundaries, villages, roads, dams and rivers are accessed from the geology department in one of the known universities in the region and the location of hospitals, health centers and health posts are downloaded from the WHO geo-network database. Those shape files from Mekelle University and from WHO are referenced in different coordinate systems. Because of this it was not possible to overlay those different data with one another to make associations across them and to do our analysis.

Fixing this problem was a big challenge for the author. Normally ArcGIS can re-project the coordinate systems of layers for display purposes had the metadata about the coordinate system been available. But the data from Mekelle University comes with no Meta data and no coordinate systems defined, no coordinate units specified, no projection information and no datum information

To solve this problem and to prepare the data for analysis, the author was forced to try so many techniques including trying to set the data to different coordinate system which is not the inherent coordinate system of the data , but this did make the problem worse and confusing. So the data has been set back to unknown again. Another attempt that has been tried was to transform the coordinates of datasets on the fly using the coordinate system listed in ArcMap Dataframe. For one of the dataset (the district boundaries) , it was managed to draw the data on ArcMap after transforming it on the fly and was helpful since it let us to experiment with various coordinate systems on the layers that are transformable and with that we managed to align the layers from the WHO data (health institutions which have metadata information) with the unknown one (the data from Mekelle University) . But this does not last long, new layers created from the datasets that have new coordinate system transformed keeps not to align with other new layers. In addition even the file has been saved, but the ArcMap does not save the new coordinate systems.

Literatures on GIS ((Dent 1999; Longley 2005) states that coordinate systems of all layers having projected (not latitude and longitude))needs to be defined , and these definitions need to be embedded into the data layers , and also discus all the techniques we tried above in an attempt to asses the situation with layers that don not align. But none of the suggested methods worked for us. Finally the problem was posted in a GIS discussion forum website (http://gislounge.com/gis-forums/) and some participants discussed to try to measure some know points. Using the information form the GIS forum participants and the literatures the author figure out the coordinate system of the data. This has been done by trying to measuring the length of two village locations and figure out the inherited coordinate units of the data. The units found to be in meters, and then based on the coordinate units we proceed to guess the projection as UTM and the datum to be WGS 1984. After we figured out the coordinate system and projections for the data we used ArcCatalog to embed the information by accessing the field properties in ArcCatalog and edit the Spatial Reference Property.

Initially the shape files for all of the health institution and for the dams collected was at the country level (for the whole of Ethiopia). ArcMap Select By Location dialog Box was used to select those features (health institutions, dams) which are within the Tigray region

.As a result of this operation new layers are created ,such as Tigray hospitals layer, health center layer, health post layer and Tigray dams layer . The major functions used in the GIS analysis for this study comprised of buffers, select by attribute, select by location, field calculator and table join.

Preparing data for analyses: *Conversion of point data into a shapefile*

The data collected for the dam locations were initially in excel format with GPS coordinate data . And this excel file comes with field names SITE, EASTING and NORTH as it shows in the following example

SITE	EASTING	NORTH
1,	413436	1580511
2,	530227	1469066

Table 4.7 GPS Coordinate examples for Dams in Tigray

This information had to be converted into shapefile in order to be viewed in ArcMap layer and to be used for analysis (e.g. to do buffer analysis). In order to do this the following steps have been followed. The data was initially in excel 2000 format but ArcGIS 9.1only recognizes excel 2003 or 2007. The first step on converting the GIS point data was to save the file in excel 2007 format and added to Arc Map using the Add XY Data Window from The Tools Box. At this point, specifying the coordinate systems that was originally used to collect the data was required. But, as it was discussed in section 4.5.5 this data and all the data from the university comes with no coordinate system or Meta data information. So to solve this we have followed the same step that was discussed above. That is by trying to measure the distance of two dams and figure out the coordinate units used. This led us to guess the coordinate system and the projection. After we add the data to ArcMap, the next step was exporting the GIS point layer to create a shape file out of it that can be used for analysis later.

Preparing data for analyses: *Preparation of the non-spatial data for analysis*

The next step was to prepare the data in the spreadsheets that would later be joined with the GIS district shape file. Much of the preparation was done in the initial spreadsheet. However, that data required further manipulation upon receipt in order to tailor the information for the various types of maps. The malaria incidence data was collected initially as total values. To make the total value in to more useful information and to make it useful for our analysis, ratio, rate and proportional indicators are calculated out of it. A common field Id was created in all the excel files to be joined and in the target spatial data. The field (column) headings of the excel files have been checked to conform that they are created by the naming guidelines required by ArcGIS .

Constructing Maps (executing the analysis)

The analyses was executed by joining the information gathered in this study to the ArcMap application in ArcGIS 9.3.1 and joining the necessary excel files to the layers based of the common field created on the attribute and excel tables. We will explain this step using the preliminary map we created to show the distribution of health facilities in relation to population density from 2004 data. Figure 4.4. outlines the steps performed in constructing the preliminary map.

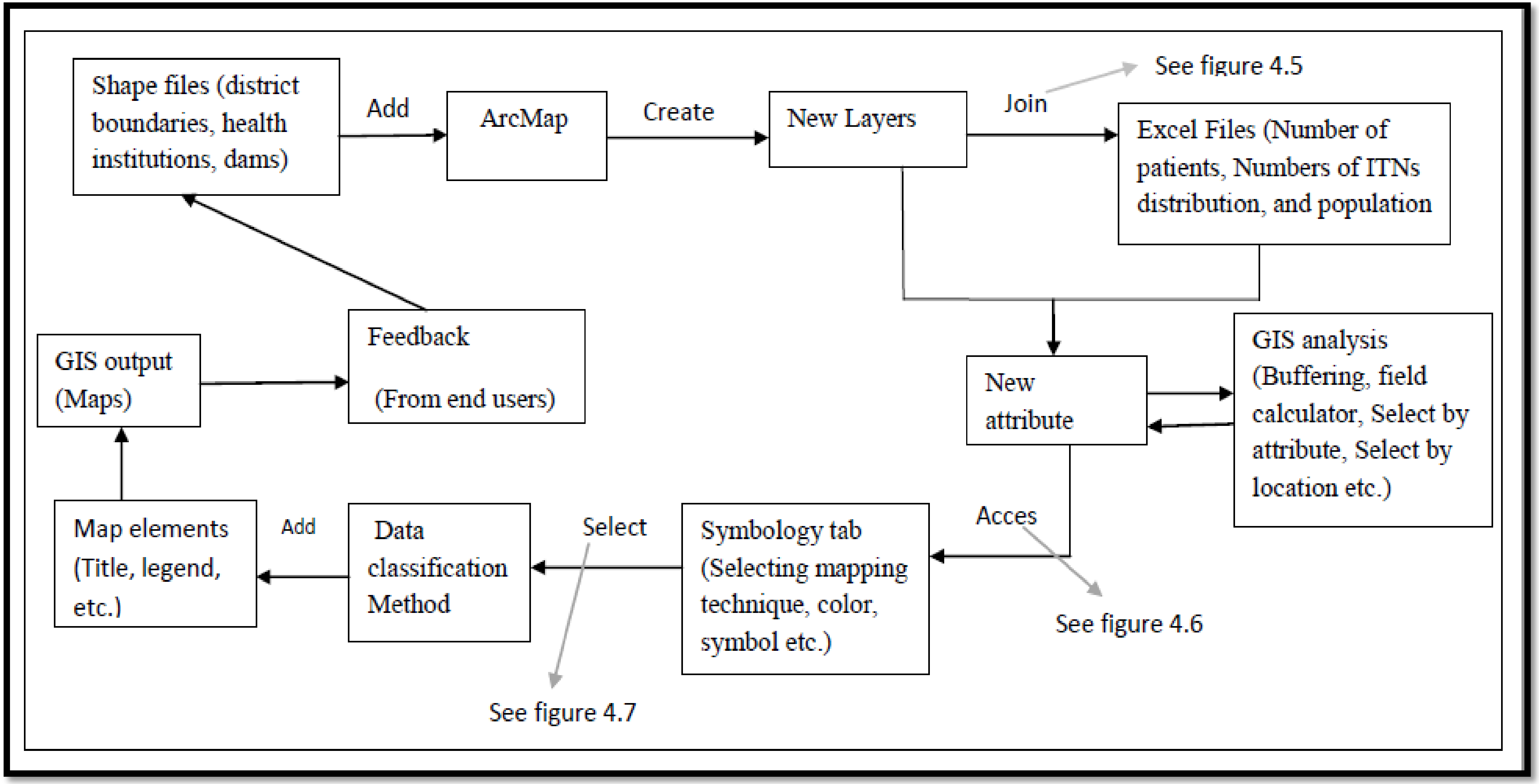

Figure 4.4 Steps in excuting the Analysis-Map construction

First, the downloaded district shape file was added to the Arc Map application. Next, the three layers which contain point locations of (hospital, health centre, health post) were added to the Arc Map application. Then the excel file 'malaria cases' which contains information on number of malaria patients and population information with data elements (total malaria patients, total malaria death, number of hospital admitted patients, and total population) was joined to the district layers based on a common field id that was created on both files on preparation of the data as it shows in Figure 4.5.

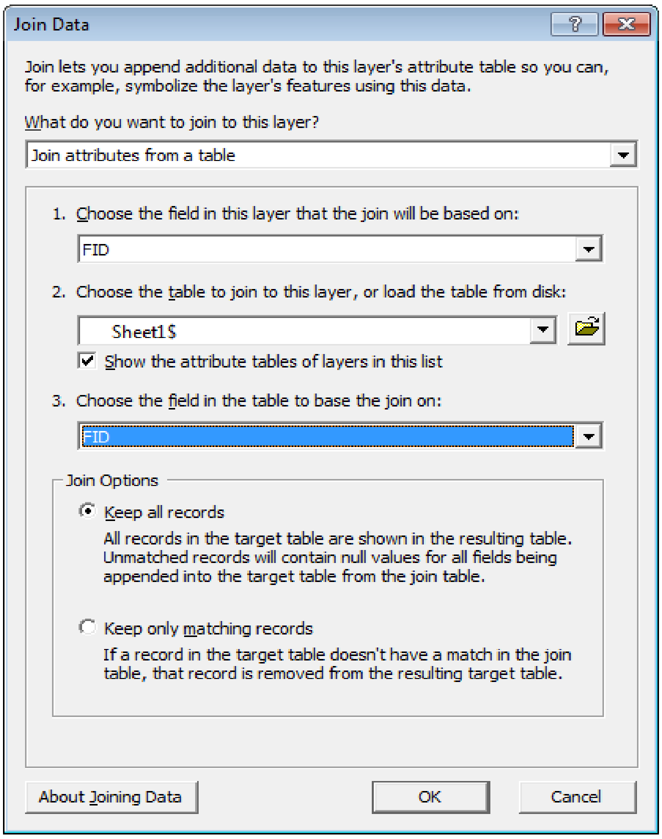

Figure 4.5 Merging spreadsheet data in ArcMap

Next, population density was calculated using two steps. First a new field was added to the combined attribute table created as a result of joining the tables. We gave a name for the new field as'P_ Density'. This step is chosen to be done after the join of the two tables because the district shape file contain area information for each of the districts and since the excel file for malaria patients contains total population information, it was easy to calculate it after joining the two tables. Next based on the field calculator box, the population density was calculated as population over area of the district in SQkm.

Next , the symbology screen was accessed through layer properties and the quantity field was accessed to view the population density by graduated color .The value field selected was ’PopuPerSqKm’, in order to view the population density as it shows in figure 4.4.

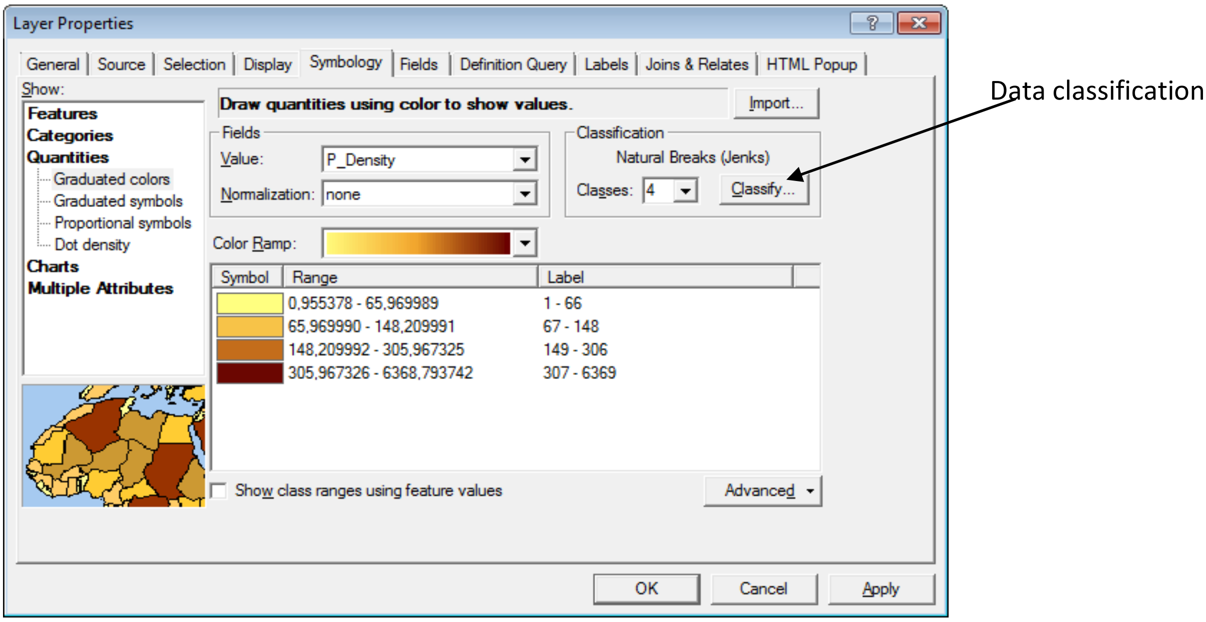

Figure 4.6 Layer Properties Displaying Graduated Colors

Next .the data classification screen was accessed in order to choose the appropriate data classification method from the listed chooses on the ArcGIS software. For the case of the population density, Natural Break classification method was chosen.

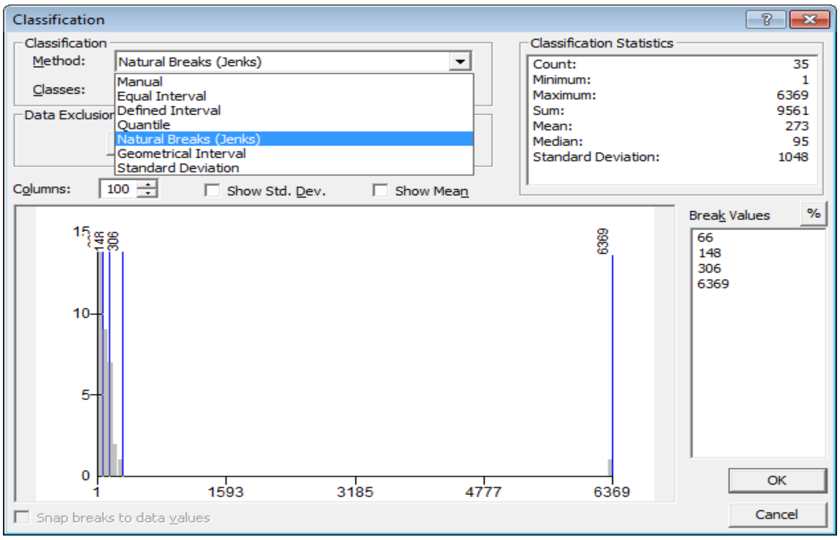

Figure 4.7 select data classification method in ArcMap

On a different map which is a continuity of the above map, the analysis tool on Arc Map was accessed to buffer analysis in order to calculate a 10 meter catchment area distance from any of the health facility locations. The rest of the maps created for this study were constructs with a basic similarity as the previously described map. But depending on the purpose of the map, different analysis was performed on each of them.

5. The Map Design Process

As the main objective of this project is to identify maps that are useful in regional malaria management programs and show effective ways of designing them, this chapter demonstrates on how maps should be designed and constructed in an effective and informative way based on the map designing principles[1]. In this chapter we will demonstrate the map designing process and the next chapter will present the different types of maps that are predominantly used as effective tools in a malaria control programs using geo-statistical data from Tigray region of Ethiopia.

To be able to explain in detail the way those maps are designed and constructed in consistency with the map communication model of Slocum et al (2009), we follow the same steps in this section in demonstrating the effective and informative ways of designing and constructing maps. As it is shown in figure 3.2, the map communication model contains five idealized steps which should be completed before finalizing the design process of any map and before the intended audience start to use it. Those are: 1) Considering what the real world distribution of the phenomenon might look like; 2) Determining the purpose of the map and its intended audience; 3) Collecting data appropriate for the maps' purpose; 4) Designing and constructing the maps; and 5) Determining whether users find the map useful and informative. As step four of this model is complex and contains various procedures that should be taken in to consideration, section 5.1 will focus on explaining the first three steps in the map communication model before we proceed to a detailed analysis of step four (techniques of designing and constructing the maps) under section 5.2. Section 5.2 includes procedures on 1) Identifying an appropriate scale and map projection, 2) Selecting appropriate map designing techniques, 3) Choosing appropriate data classification method, and 4)

Identifying map elements to employ and decide how each will be implemented. The final step of the map communication model which is , evaluation by the intended user on the effectiveness and attractiveness of the different designs of maps in this project will be discussed in chapter seven after we demonstrate the main map typologies designed and constructed as an informative tool for a malaria management scheme (chapter 6).

[1] Please see chapter 3 of this project for detail description of the different map designing techniques.

5.1 Step 1 - 3 of the Map Communication Model

Considering the real world distribution of the phenomenon

Step 1 of the map communication model requires that we consider what the real world distribution of the phenomenon (i.e., malaria with reference to this particular study) might look like. Besides other drivers of malaria epidemiology, topography is likely to have a major effect on spatial vector and parasite distribution. Many of the factors important to mosquito development and survival, such as meteorological conditions, vegetation, water body characteristics and land use may be related to topography (mainly landform and elevation). The topography of the highlands of Tigray comprises hills, valleys and plateaus. Rivers and streams run along the valley bottoms in the valley ecosystem and swamps are a common feature of these lowlands. Unlike in lowland plains of the region, where drainage is poor and mosquito breeding habitats may have an extensive distribution, the majority of breeding habitats in the hilly highlands of Tigray can be confined to the valley bottoms because the hillside gradients provide efficient drainage. Moreover, the level of malaria risk could also be highly correlated with the presence of micro-dams.

The existing literature on the epidemiology of Malaria in Tigray supports our argument. Researchers from the Tigray Regional Health Bureau and the UK University of Nottingham studied over 7000 children to assess the incidence and distribution of malaria in Tigray (Ghebreyesus et al, 1999). According to their findings, malaria is seasonal and the overall incidence is low in the highlands of Tigray regional state. Malaria was found to be more common in the lowland villages at an altitude below 2000 metres. On the same note, malaria incidence in the villages close to dams was reported to be seven times higher than in villages without dams.

Determine the purpose of the map and its intended audience

The second step of the map communication model requires us to determine the purpose of the map and its intended audience. For all the subsequent maps included in this project, the intended end-users are, mainly, regional malaria managers, malaria experts/researchers, public health managers and the general public. For instance, the intended end users of the map in Figure 5.2A are, expected to be malaria experts and the general public. This map is designed to communicate the overall regional incidence and distribution of malaria comparing the 35 districts in the region. Malaria managers can make use of this map to educate the general public in order to take preventing measures and precautions. Each one of the maps in this study is designed for distinct purposes and will be discussed in due course of each section in this chapter.

Collecting of appropriate data for the purpose of the map

Step 3 of the map communication model involves the collection of appropriate data for the purpose of the map. For the whole of this thesis we collected our spatial and non spatial data from secondary sources. The spatial data contains, district boundaries of the region, location of different health facilities and location of dams . The non spatial data contains malaria related information and population data. Please see chapter 4 (Data and Methods of Analysis) of the thesis for detail description of the data sources and utilizations.

5.2. Designing and constructing the maps.

Designing and constructing the map involves selecting an appropriate scale and projection, selecting appropriate mapping technique, selecting appropriate data classification method, selecting appropriate symbol and also selecting and positioning the various map elements (e.g. title, legend, and source) for the purpose of the map. In order to accomplish those tasks one has to identify the dimension of the data; the nature of the data i.e., if it is standardized in some way or if it is still in raw totals; the characteristics of the intended audience and the specific purpose of the map. Hence, as outlined by Slocum et al (2009), the process of designing and constructing effective and informative maps can be performed in terms of four distinct procedures, namely:

1. Identifying an appropriate scale and map projection,
2. Selecting the most appropriate map designing techniques,
3. Choosing the most appropriate data classification method, and
4. Identifying which map elements to employ and decide how each will be implemented

5.2.1 Identifying an appropriate a scale and map projection:

Choosing the appropriate scale for each respective maps included in this project has be dictated by two major factors: *namely*, *i*) the need to represent all districts of the project area – regional state of Tigray, and *ii*) the need to fit the output (produced maps) in to a paper page size. Since we do not need to show much detail of the area, our experimentation has resulted in an optimal scale of roughly 1:2,500,000. The data we used in the GIS analysis phase of this project are stored in UTM coordinate system, incorporates the Universal Transverse Mercator projection. This projection correctly represents the shape of small areas, but it gives minimal distortion with large shapes. It is also possible to make accurate calculation of short distance between points because UTM coordinates are in meters.

5.2.2 Choosing appropriate map designing techniques

As it has been described in chapter 3, the literature on cartography and map designing has identified standardized data (rate, ratio, and percentage) as an appropriate for a chropoleth and isopleth mapping techniques while total (raw) data is more suited for graduate symbol and/or dot mapping techniques. In choosing choropleth mapping techniques unless the enumeration areas are all the same size, ratio, rate , density, percentage or any form of standardized data should be used , rather than total values for a given map to be meaningful. As illustrated in Figure 5.1, let's assume two areas each of which contain 5,000 people. If the two areas are highlighted according to the total population (using a raw or un-standardized data), both will be shaded alike. However, it is obvious that the density of population is greater in the smaller area as compared to the larger area and that the map is misleading when population characteristics appear equale. If the two areas are shaded according to population per square mile, ′ District B′ will show 200 people per square mile and ′ District A′ only 50 people per square mile.

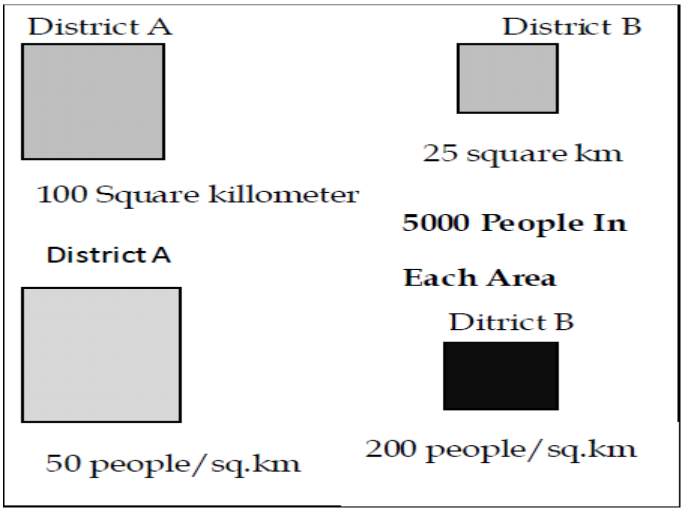

Figure 5.1 Values used on choropleth maps should be standardized (e.g., percentage, ratio, rate, or density), or the map will be misleading.

To elaborate more why data consideration matters in our decision of selecting the right mapping technique, we constructed Figure 5.2 to map a choropleth, graduate symbol and dot map techniques . For this purpose, we used an aerial data (malaria cases) for each district which is represented as: *i)* variation in magnitude of the incidence (standardized data), and *ii)* in terms of total number of incidences (a raw/total data).

Accordingly, Figure 5.2A shows the distribution of malaria patients standardized as per 10,000 populations. Figure 5.2 B represents the distribution of the actual number of malaria patients and Figure 5.2.C show the actual population distribution of each district in the region. Notice the difference in *Tahtay Michewu* and *Adwa* district in both figure 5.2A and Figure 5.2 B . From our 2004 Tigray region malaria data *Tahtay Michew* was the most malarious area with 10,263 cases from 10,091 population as it shows in Graph (5.4)[2].

In case of Figure 5.2B, which is constructed using the unstandardized (total) malaria data, both districts fall in the same category (were shaded using the same color) – showing little difference in between the two districts in terms of the severity of malaria incidences. Such contrasting evidence is more reconciled when one looks at Figure5.2C - the population distribution. Even if both districts are similar in terms of the total number of malaria cases (Figure 5.2B), such similarities are not witnessed when we compare the per 10,000 malaria incidences (after standardizing the data) which is shown in Figure 5.2A. that shows the malaria incidence per 10,000 is extremely higher in *Tahtay Michewu* as compared to that of the *Adwa* district.

[2] See Figure 4.3 for detailed information on the distribution of malaria incidences in the region

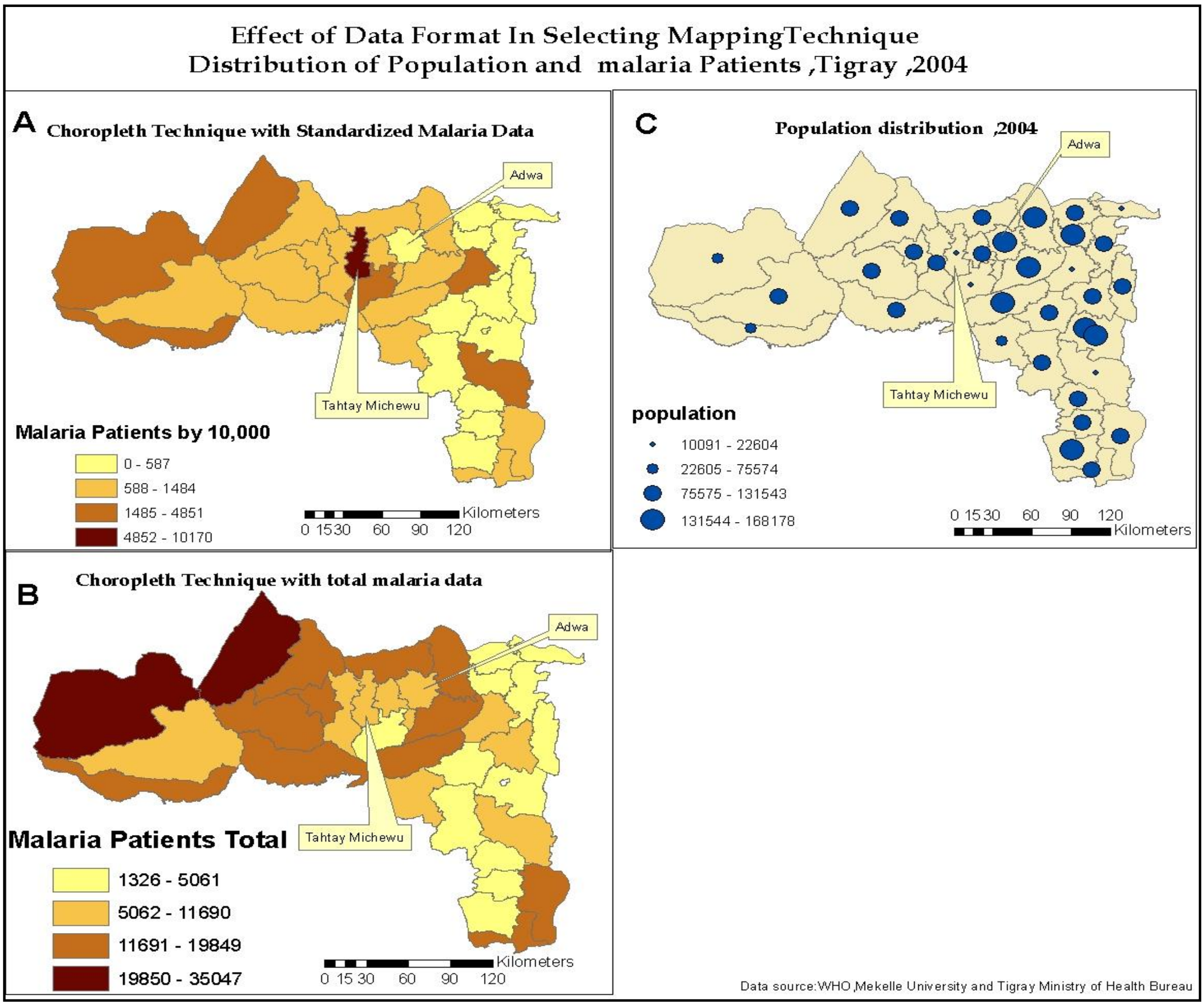

Figure 5.2 The Role of Data Standardization in Chropleth Map Designing Techniques

Figure 5.2, thus, shows designing and constructing an effective and informative map depends on the purpose of the map and who the intended user is. For instance, if we are targeting malaria managers (policy makers) as end users that are planning to target and prioritize public resources towards those areas that are severely affected the choropleth map of 5.2A that utilized a standardized data can be more informative and useful for policy relevance. In such a case, Figure 5.2B could be misleading as it fails to show the severity of the problem but only shows the overall incidence (number of cases) of malaria. On the other hand, if the intended target is a malaria expert or the general public that are more interested in the overall incidence of malaria and how to take early-warning, preventing and precautionary measures, the choropleth map that utilized un-standardized data of Figure 5.2B could be more effective and informative as it groups districts in terms of the number of malaria cases (incidences) but not the severity of the matter.

Making use of the same malaria incidence data, it is also possible to design and construct informative map using proportional symbol mapping technique. However, unlike the choropleth mapping technique, it is highly recommended to use raw data than standardized data in order such map to give accurate information. Figure 5.4(A) shows the distribution of actual number of malaria patients (raw/total data) in each district of the Tigray region. This map is useful for showing the magnitude of the malaria cases, but still we have to be careful in interpreting any spatial patterns on this map because districts with large population might have a large number of malaria patients. (There might be a correlation between Figure 5.4A and Figure 5.4 C which show the distribution of population in the region).

One method of standardization is to compute the ratio of the two total attributes – malaria cases and total district population sizes. In the case of the malaria cases data, we can compute the ratio of malaria patients to the total number of population in each district, obtaining the proportion of malaria patient's number in each district. This is shown in percentage form in (Figure 5.4B). This map has a markedly different appearance than the non standardized map in Figure 5.4A, in the large part because of a much narrower range of data: 6 to 102 percent as opposed to 1326 to 35047 cases. This map also illustrates the difficulty of using proportional circles when the data range is relatively narrow- here the largest value is more than ten times the smaller, but the map doesn't immediately suggest this.

As we can see from the above example, although standardized conceptual point data can be represented with proportional symbols, a choropleth map is more commonly used, because conceptual point data are associated with areas and also gives more clear information.

It is also possible to map this data using a dot mapping technique. Dot maps are ideally utilized when we have collected conceptual point data in the form of raw totals for enumeration units, and wish to show that the underlying phenomenon is not uniform throughout the enumeration units. As we mentioned it in chapter three dot maps are created by letting one dot equal a certain amount of some phenomenon and then placing dots where that phenomenon is most likely to occur.

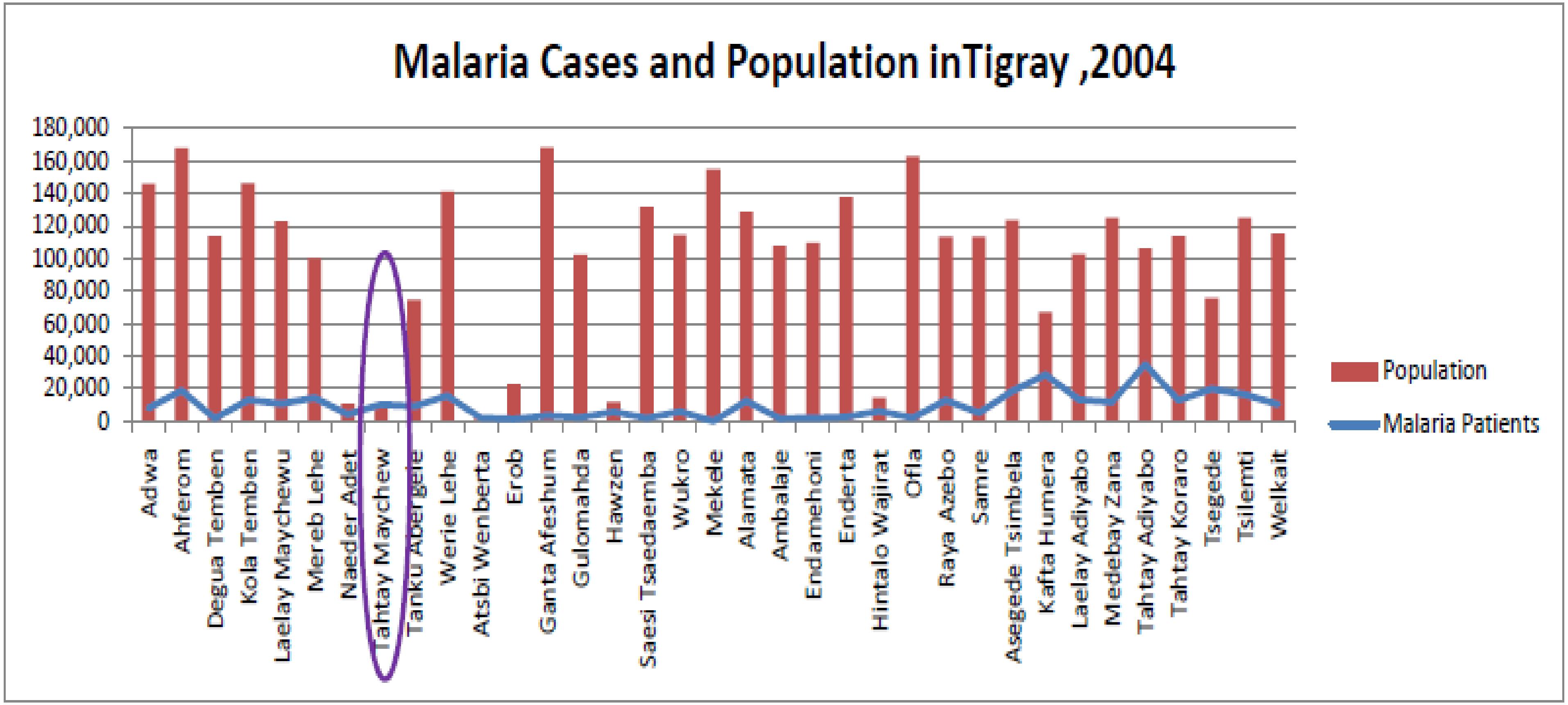

FIGURE 5.3 Number of malaria patients and population distribution ,tigray – 2004

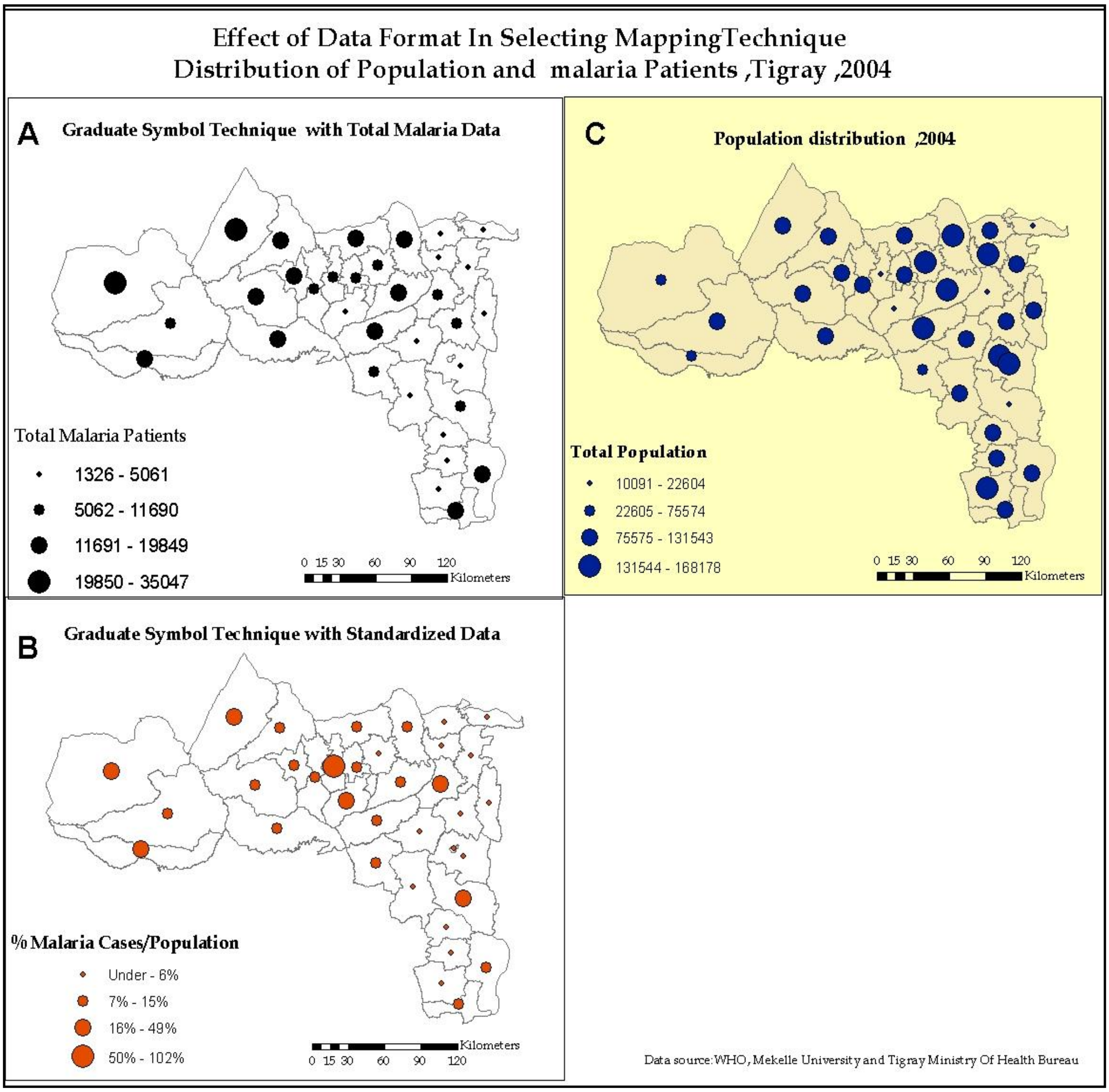

Figure 5.4 Values used on Graduate Symbol maps should be un standardized (total value) .

For instance in (Figure 5.4A) we have mapped the number of malaria patients in each district of the Tigray region using a proportional symbol, but this map would be misleading, because each district would have a single symbol, suggesting no variation in the spatial distribution of the malaria patients with in the district. We did so since we don't have detailed spatial data to show us where exactly in the district does the patient live. We created a simple dot map in Figure 5.5 to show the distribution of malaria in the region. The map immediately suggests which districts have high concentration of malaria cases and on which ones have sparse distribution. From the above explanation it is obvious that the appropriate data to be mapped using dot map technique should be raw total. Mapping standardized data with dot map technique does not give sense. The map in Figure 5.5 suggests that malaria cases are spread throughout each district in unevenly manner.

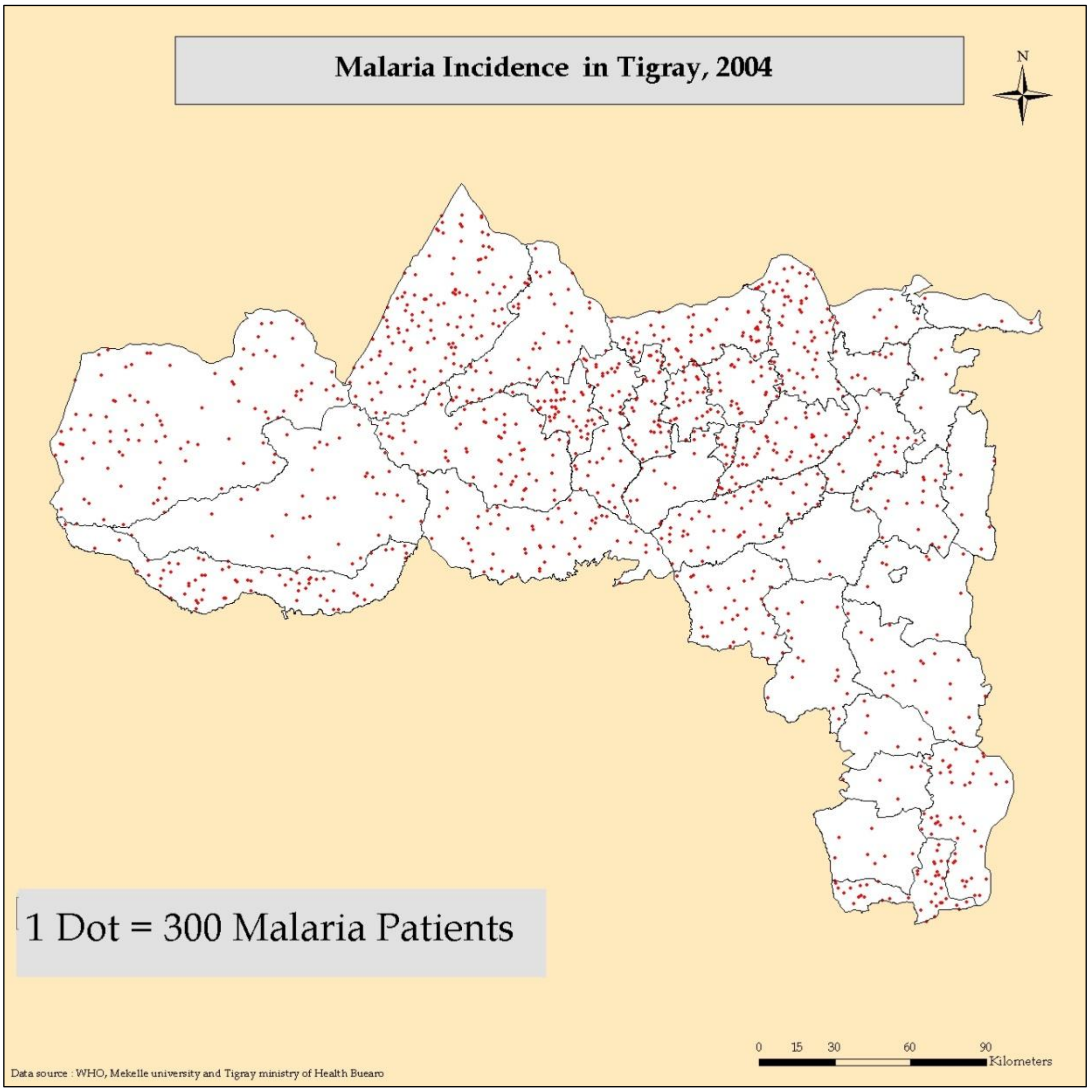

Figure 5.5 dot maps of malaria cases in districts of Tigray region.

The intended audience for the map in figure 5.5 can be Malaria experts or researchers who want to see the distribution of the disease and do farther research to identify potential factors for why some of the areas have dense malaria cases. However such maps must be interpreted with caution since the underlying population also various spatially. Disease occurs where people are, any apparent cluster could simply be due to a large concentration of residences in a given area. This could be the situation conveyed in figure 5.5 where the large concentration of malaria cases correspond to the districts which have high population as in Figure 5.4C. Note that dot maps of data that are not based on population (e.g. dot maps delineating the location of hospitals) do not have this kind of interpretation problem.

As we have seen above the appropriate selection of mapping technique depends on the type of our data, the purpose of our map as well as the characteristics of our audience. When it comes to mapping disease rates , pickle et al. (1994) report that epidemiologists prefer classed choropleth maps and used them more accurately than other mapping techniques. Because of this we expect classed choropleth maps to be used more in malaria mapping as well.

5.2.3 Choosing the appropriate data classification method

Producer 3 of the map designing process requires as choosing the most appropriate data classification method for the purpose of the map. When we design a map using choropleth and graduate symbol mapping technique, one of the first decisions to be made deals with data classification: which values should be assigned with each color or with which symbol. In other word , which units should be in the lowest class, which units should be in the highest class, and how the rest of the units should be distributed among the remaining classes. Data classification decisions is among the most important to be made in map designing, but also difficult to understand. As a map designers we must make choices about how many different classes that the data should categorized into and what the value range of those classes should be. A slight adjustment of the class breaks in the values ranges of ordered data might alter the map significantly and might reveal trends that were not detected previously. As it shows in figure 5.7 different data classification methods produce different patterns for the Tigray malaria data. For all of the malaria incidence data in this study, we choose natural break data classification methods with four different data values, because as it shows in figure 5.7A Natural Break method minimizes the difference between data value in the same class and maximizes differences between classes - which means it will categorize similar values of the data in one and the extremes in different class. For instance, if the highest value in the data is different from rest of the data, then it will place it in a separate class by itself. The four categories of data values are chosen because it is widely used in statistical analysis.

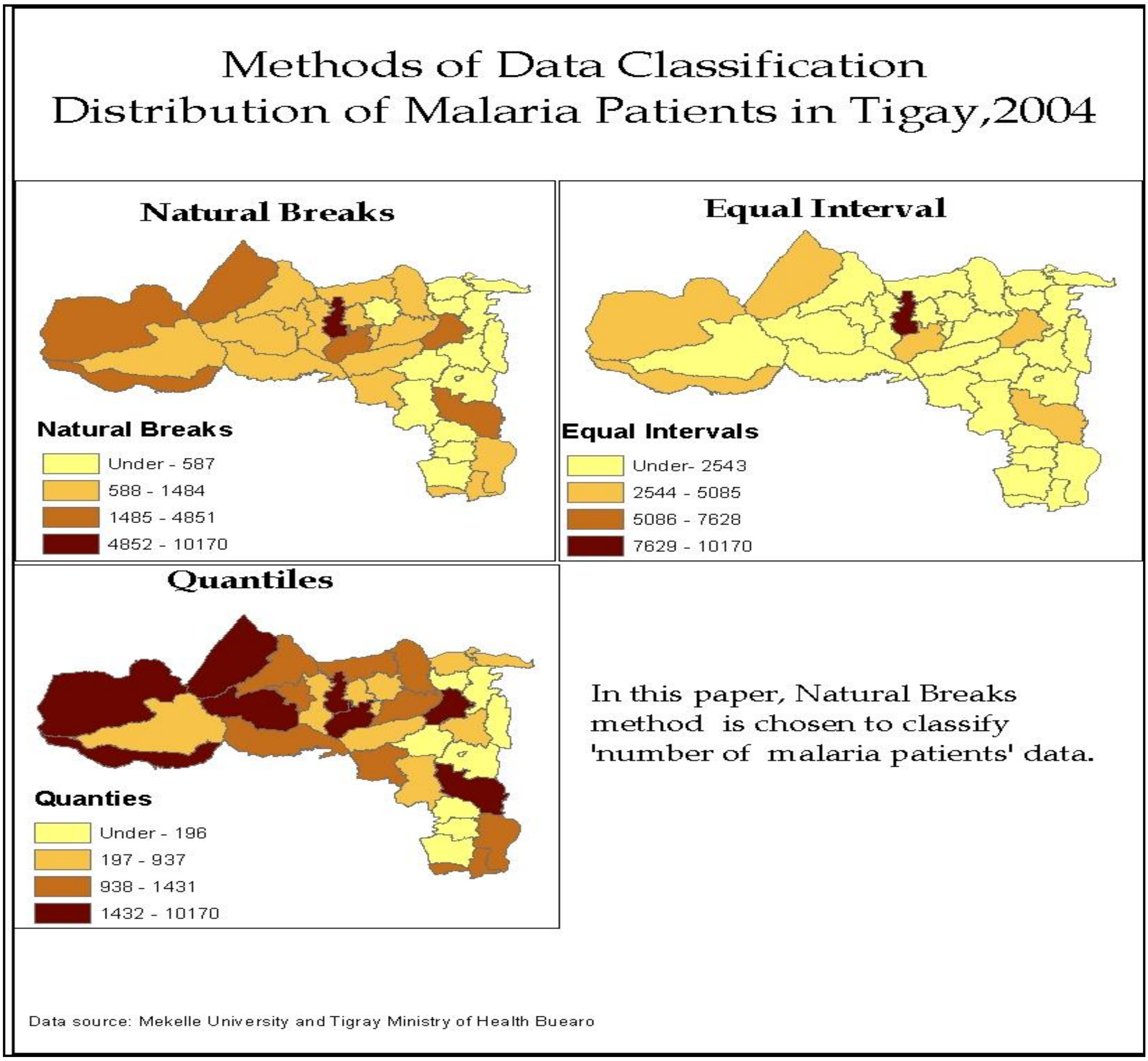

Figure 5.7 Choropleth maps illustrating various methods of data classification for the malaria incidence data form Tigray, 2004

5.2.4 Identifying which map elements to employ

Procedure 4 in the design process involves the selection of the appropriate map elements, and consideration of how they should be implemented. “Map elements represent the building black of map communication which is the transmission of geographic information through the use of maps” (Slocum et al. ,2009). Effective use of map elements and layout enhances the goal of our map. For all the maps designed for this thesis , we have decided to include the , a title, legend, scale, explanatory text, directional indicators, sources, credits, border ,insets, and locator maps.

Border (Neat line)

The first map element we placed for all the map elements was the border (neat line). It is included because it can help focus the map user's attention on what is within it. The frame line also helps us establish the initial available space, within which all other map elements will be placed. A solid thin black line (0.5 point) size was used to help it serve its purpose without attracting unnecessary attention**.**

Title and Subtitle

The title will succinctly reflect the maps theme. We believe we used an appropriate title for each of the maps which can clearly describe the goal of the map. We also used subtitles to explain the name of the region and the information about the data collection date for the attribute data used. The title is the largest type on the map followed by the subtitle and legend heading. To increase readability, we slightly increased the letter spacing and word spacing.

The legend

The legend is one of the most important map elements that are key to interpret the map. We use a subtle bounding box around the legend on all of the maps to mask the underlying mapped area and to organize all the thematic symbols which are used on the map. We have defined all the symbols which we think are not self explanatory on the legend. We also give extra care to ensure that the symbols in the legend are identical to those found within the mapped area. We make the size, color and orientation of the symbols to be the same on the map area and on the legend box. We include all symbols of each map in the legend. For consistency reasons, we make all types of characteristics in the legend identical to those used in the title, subtitle, and data source, with the exception of type size. The legend heading are visibly smaller than the subtitle, and the legend definition is smaller than the legend heading.

Data source

The data source indicates the source for the GIS data and the attribute data used on all the maps. We include the data source information on each of the maps with the heading data sources to avoid confusion with map authorship and publication information.

Scale

We include a bar scale because it will allow the map user to assess the neighborhood characteristics, such as proximity to the nearest health facility, dams or rivers. The scale for all begins with zero and the maximum distance is 120 km – a value that is round and easy to work with. We also adopted kilometer as a unit of measurement because people in the region are more familiar with it than with miles or other measurement. We make it easy and informative but it doesn't attract much attention on the map.

Direction Indicator

For the sake of orientation, we include a north arrow which indicates the north on the map with a simple star and N to indicate the north.

6. Types of Maps for Malaria Management

As it has been discussed in section 3.6, GIS technology provides a powerful tool for management and analysis of malaria control program. According to Sweeney (1998), the use of this technology can be customized to suit a wide range of applications in malaria management, namely: 1) as an operational planning aid tool; 2) as program evaluation tool; and 3) as a malaria research tool.

As far as the role of GIS as operational planning aid tool is concerned, practical operational maps can be created to assist resource allocation and to provide information related to health service. For instance, maps can be generated to access health service information which includes *availability* of health service (supply of service in relation to needs); *accessibility* of health services assessing possible geographic barriers including distance, transportation and travel time to get service; *accommodation* of health service that identifies the degree to which services are organized to meet clients needs including hours of operation ,waiting time to get service; and *affordability* of health service which refers to the price of service in regard to people's ability to pay. Service availability maps provide an over view information to health managers in identifying areas in need of more health facility. Service accessibility maps can assist health managers and malaria control experts in allocating resources (drugs, man power, insecticide treated nets, etc) efficiently. Malaria management experts can plan on doing pre-malaria intervention measures on remote and seasonal malaria endemic areas which are far from any health service. Maps with service accommodation and service affordability information can provide an overview information to the general public in choosing the right health service provider based on hours of operation, waiting time and price affordability information.

Considering the role of GIS as a monitoring and evaluation tool, maps can be created with the aim of monitoring disease causes and to assist evaluation of control/intervention measures. A map can be generated with the aim of providing information about malaria incidence in relation to water body, dams, rivers and assess if the existence of those water bodies have effect on the malaria incidence in that specific area. This information can help the malaria control program managers to monitor the situation and make an informed decision on alternative preventive and precautionary measures. Geographic data availability can also help generate maps with the aim of evaluating the effectiveness of program interventions which have been taken place. For instance, a map which displays the insecticide net distribution in combination with malaria incidence in time sequence can help the malaria control experts to evaluate its effect in minimizing malaria incidences. To facilitate the program monitoring and evaluation, maps can also be designed with one or more dependent variables to show change over time.

This study shows useful types of maps that can be created in controlling malaria management using GIS mapping technique. In line with the aforementioned roles GIS technology plays in a malaria management programs, we categorized different sets of maps in to four major groups, namely: 1) *Health service maps* - maps that present information related to availability and accessibility of health service centers; 2) *Trend map* - maps that give information about changes over time; 3) *cause and effect maps*; and 4) *malaria incidence maps* - maps that show the geographic distribution of the disease.

Variables	(Malaria) Health	Health Service	(Population) Demography	Potentially Determinant Factors	
				Nets Distributed	Dam Locations
One variable	Fig. 6.14				
One variable comparison	Fig. 6.8				
One variable over time trend	Fig. 6.16				
Multiple variables	Fig.6.2 Fig. 6.12 Fig. 6.15	Fig.6.2 Fig. 6.3 Fig. 6.1	Fig. 6.3 Fig. 6.1		Fig. 6.12
Multiple variable comparison	Fig. 6.13				
Multiple variable overtime trend	Fig.6.7 Fig. 6.13		Fig.6.7	Fig.6.7 Fig. 6.13	

TABLE 6.1 Overview of Maps Developed

6.1 Health Service Maps

One of the key goals of public health administrators is to make essential health care services equally accessible to all individuals and communities. The most basic information on the availability and accessibility of essential health services and health resources is often incomplete especially in Tigray region and Ethiopia at large. Using the power of GIS, it is possible to get information about the distribution of health services, health resources, and availability of access to service and services offered within and across a geographic area of districts. For example we can use GIS to collect information and produce maps representing the distribution of health personnel (doctors, nurses), health care centers (hospitals, clinics) ,antiretroviral therapy (ART) sites, condom distribution sites, tuberculosis (TB) treatment sites, local malaria control sites, computer accessibility, internet accessibility, accessibly to safe drinking water and many more. In Kathy O'Neill (2007), those types of maps which are created to assess health care coverage have been discussed as output of service availability mapping (based one WHO HealthMapper software). Some of the examples given in her paper include a choropleth maps showing the number of doctors, location of therapy (ART) sites, and a map showing the location of sites providing tuberculosis(TB) diagnosis from a 2006 data in Zambia. Likewise, Martin et al(2002) and Chris Wayne (2002) have created a similar maps to show the location of homesteads with respect to distance to health facilities and distribution of hospitals respectively. Even though all those maps have been designed with various distinct purposes, the general purpose of all is to present basic information on the availability of health service centers. Based on this, we give a group name called "Health service maps "for those maps that are designed with the purpose of showing any health service information.

Below we have designed three examples of health service maps, with each having their own specific purpose using the available data we have from Tigray region of Ethiopia. Figure 6.1 shows the distribution of health facilities (hospitals, health centers, health posts) in combination with population distribution of the region in all the districts.

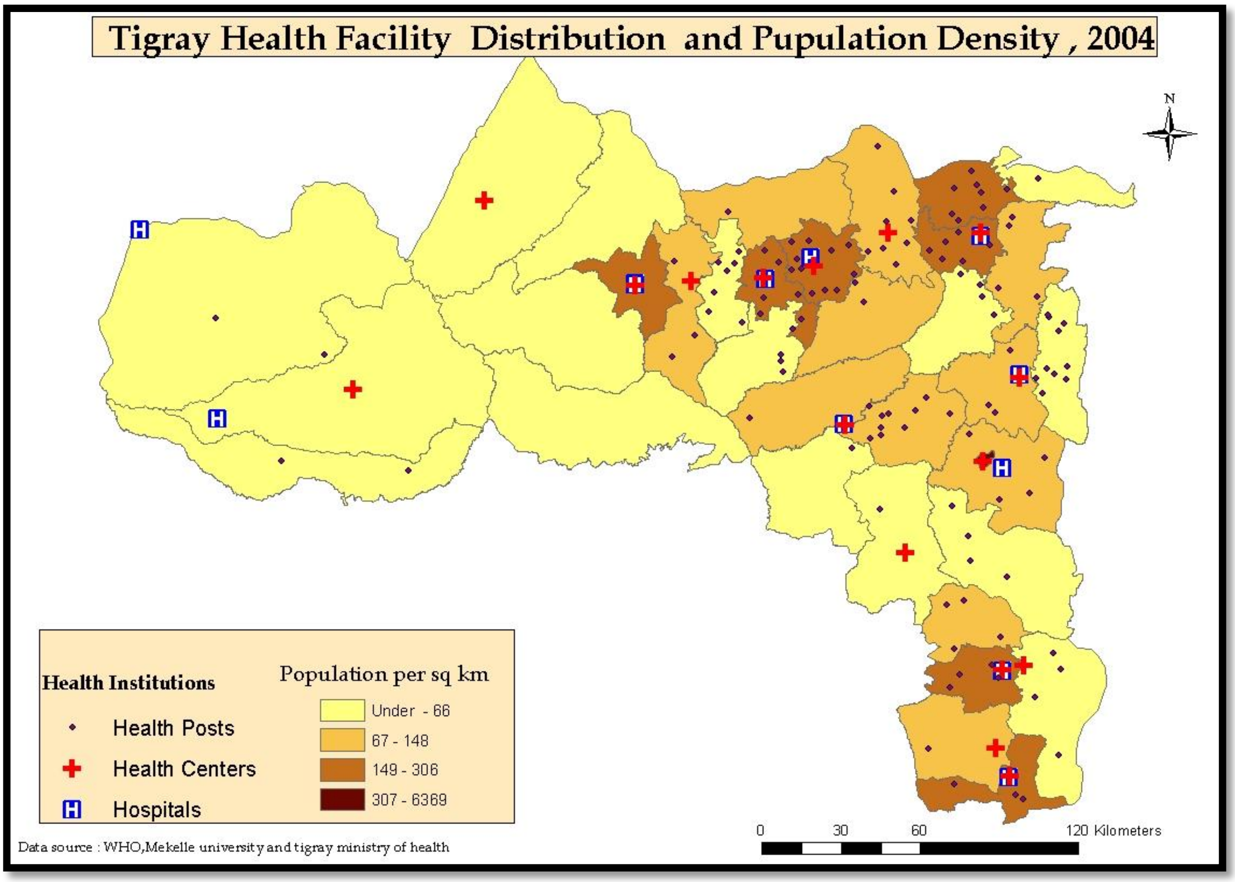

Figure 6.1 choropleth map showing the distribution of health facilities(hospitals, Health centers, health posts) in Tigray region in combination with population density per km^2

The specific purpose of this map is mainly to show the health facility distribution in the region and to see whether most of those health facilities are in more densely populated areas or not. Because our population data is collected as aggregated data for each of the districts in the region and since those districts does not have equal size, we choose to design this map using the choropleth mapping approach. The population data has been manipulated to give more correct information as standardized data (population density) and in order to be more appropriate to be used for the technique we choose. Each district is symbolized with a color value that gets darker in relation to increased number of population density. The data is classified using natural break data classification technique. For the health institutions symbol by resemblance (capital H using blue background for hospital and + sign with red color for health center) and symbol by relationship a dot symbol (.) assigned to represent health post) has been used. The reason why symbols by resemblance are chosen is that because it makes it easy for the map reader to understand the symbols even without seeing the explanation in the legend. But since everybody might not understand it easily, we decide to include it in the legend. The map can provide an important overview for health managers to see where they need to build more health facilities.

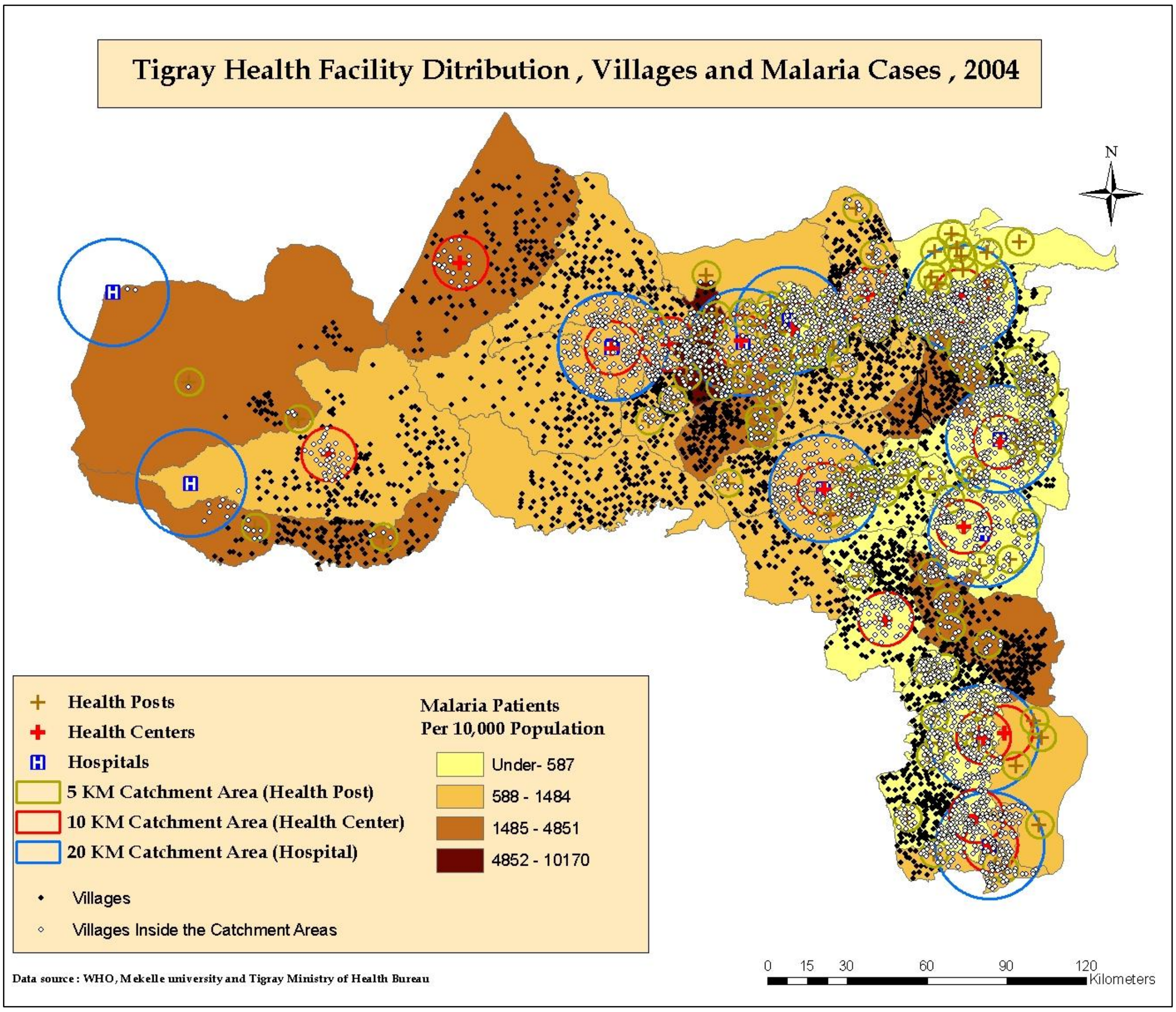

Figure 6.2 Choropleth map showing distribution of health facilities with their limits of their catchment area , and malaria patients per 10,000 populations in Tigray region (data 2004).

The purpose of the map in figure 6.2 is to show how much of the villages are out of reach of health facilities regardless of their population size. Two malaria experts who have given us feedback on the design of our maps have suggested calculating the number of population within those catchments areas and to compare and see how much of the population is out of those catchment areas. But we were not able to calculate the expected number of population within the circle of the catchment areas, because the population data we have is at district level not at block level. In figure 6.2 with the addition of the villages, though we don't exactly know how much population lives in each village it is still possible to anticipate how much of the population lives far from any health institution since a significant number of villages are without any health facility and very far from any health care service. Villages are localy called kushets and usually contain 100 to 160 households with average household size 6.2 and population ranging from 600 to 1000 (WHO review,1999).

For the map in figure 6.2 the choropleth mapping technique is utilized because the malaria data is collected for all the districts in the region and we standardized it as malaria patients per 10,000 persons in order to give correct information for the technique. The natural break data classification method is chosen in order to show us clearly if there is a district which is more malarious than the other districts. The **color value** is used to show quantity difference in the data. Dark color show more malaria patients and light color shows less number of patients. For the health facility distribution, symbol by resemblance has been used to show the different point data (hospitals, health centers and health posts) and symbols by relationship to portray the villages.

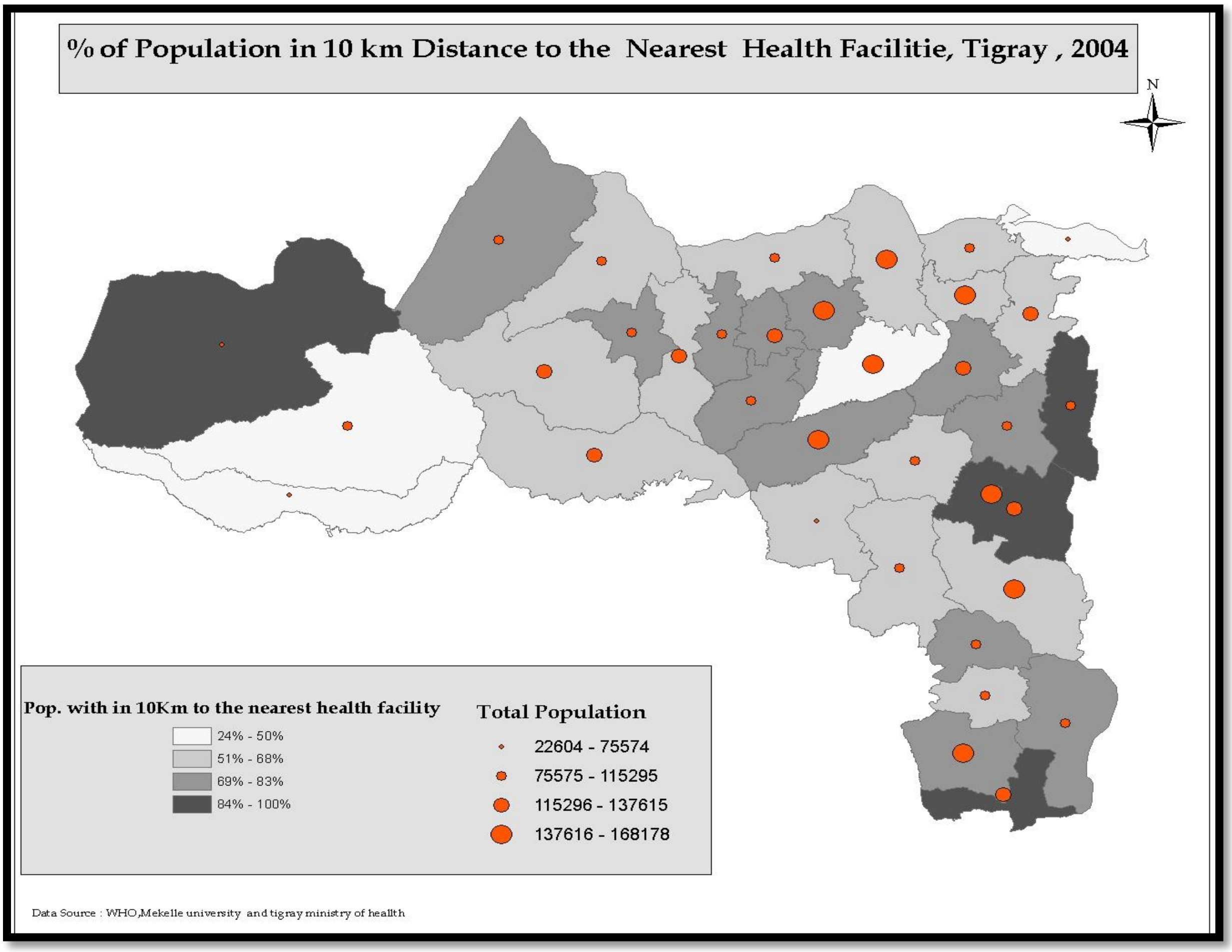

Figure 6.3 A map showing total population living in each district and how much of them live within 10km distance to any nearest health facility.

Figure 6.3 contains vital information which can be used to identify those affected villages that are beyond the reach of health facilities and therefore in need of outreach workers to ensure that every cases of the disease is contained. Malaria program managers can use this map information to plan and target interventions and to ensure the most efficient use of resources.

The purpose of the map in figure 6.3 is to show how much of the populations in the region have relatively easy access to health care service. The 10 kilometer distance is used to assess this because we get a tabular data from the ministry of health with this information. For the same reason that we explained for figure 6.2 , we were not able to calculate the number of population which resides inside the different catchment areas of the health institutions.

The map in figure 6.3 is a multi variant map which is designed as a combination of choropleth and graduate symbol mapping technique. The total population number for each district is symbolized using circle graduate symbols with difference in size . The bigger the size of the circle shows that the number of population on those areas is high. The data to show number of population with in the 10 km distance to the nearest health facility has been standardized to be in percentage and portrayed using choropleth mapping approach. Color value is used to show the order in the percentage different of those people who live near the health facilities. The map can provide valuable information to health managers by showing the percent of population which resides far from a reasonable health care coverage in the region.

In all the above three maps GIS has contributed as a planning aid tool, since our main target audience for those maps are the health managers those maps can provide them an important overview to where they need to build more health institutions

6.2 Trend Maps

Trend as its dictionary definition implies is something that shows the general direction in which something tends to move. So, when trend maps are created we expect to show a change in time interval from the data. Many disease maps have been created with the aims of trying to show the trend. In U.S an animated trend map which shows a serious of maps displaying dynamically in sequence for each consecutive year has been developed in order to show obesity prevalence over adults for 20 years from the year 1986-2009 (figure 6.4). The obesity map is developed by the centre for diseases control and prevention (CDC) organization based on data collected through the CDS's behavioral risk factor surveillance system (BRFSS) for each year. The map is designed using choropleth mapping technique having seven classes starting from white color with no data states to dark red color for the highest which is > 30 obesity prevalence.

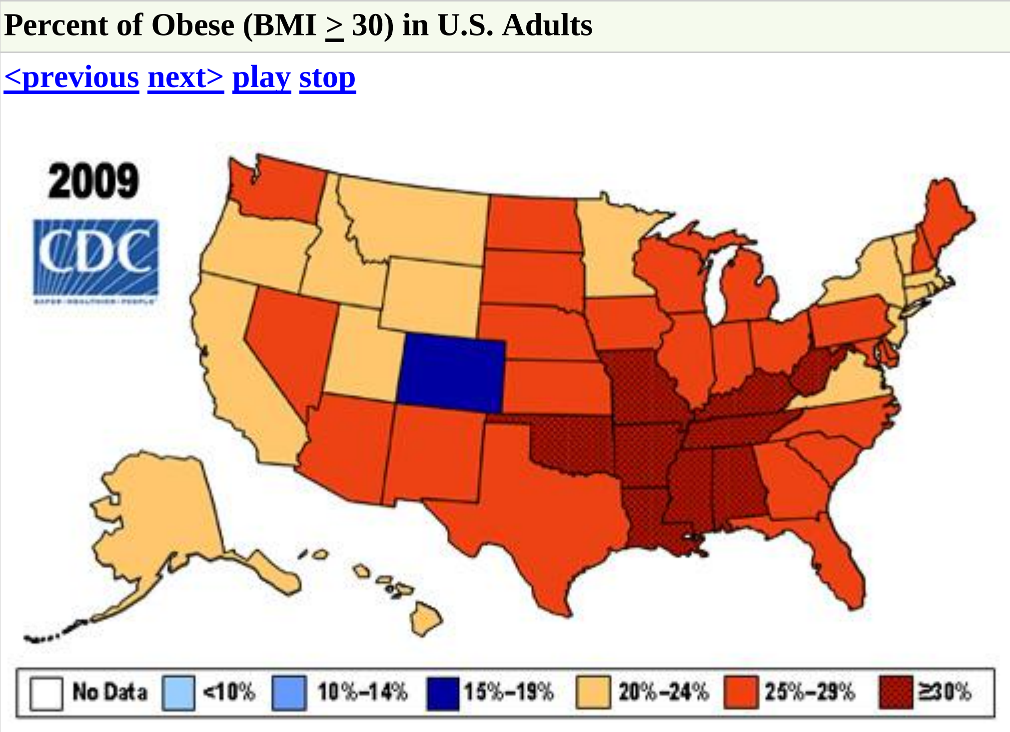

Figure 6.4 The interface of obesity trend maps for adult prevalence in USA[3].

Likewise, a Set of static maps has been created to describe the pattern and trend of malaria incidence along the Thai borders in Thailand for the 11 years from 1991 to 2001 as it is shown in figure 6.5. The maps were developed based on secondary data which was collected monthly for all of the years 1991 to 2001 at national level by Bureau of Vector Borne Disease, Department of Disease Control and by ministry of public health in Thailand (konchomo). As we can see from the figure, the map is designed using choropleth mapping technique with nine classes. The classes are shaded with a color value starting white for no data districts to dark red for districts with highest malaria incidence. With nine classes it is

[3] By clicking the previous or next button on the top, the maps show information from a different year Source: http://www.cdc.gov/obesity/data/trends.html website

difficult to easily understand this map for the map reader. In practice not more than six classes are recommended, and a minimum of four is also a good practice (Dent 2009, p163).

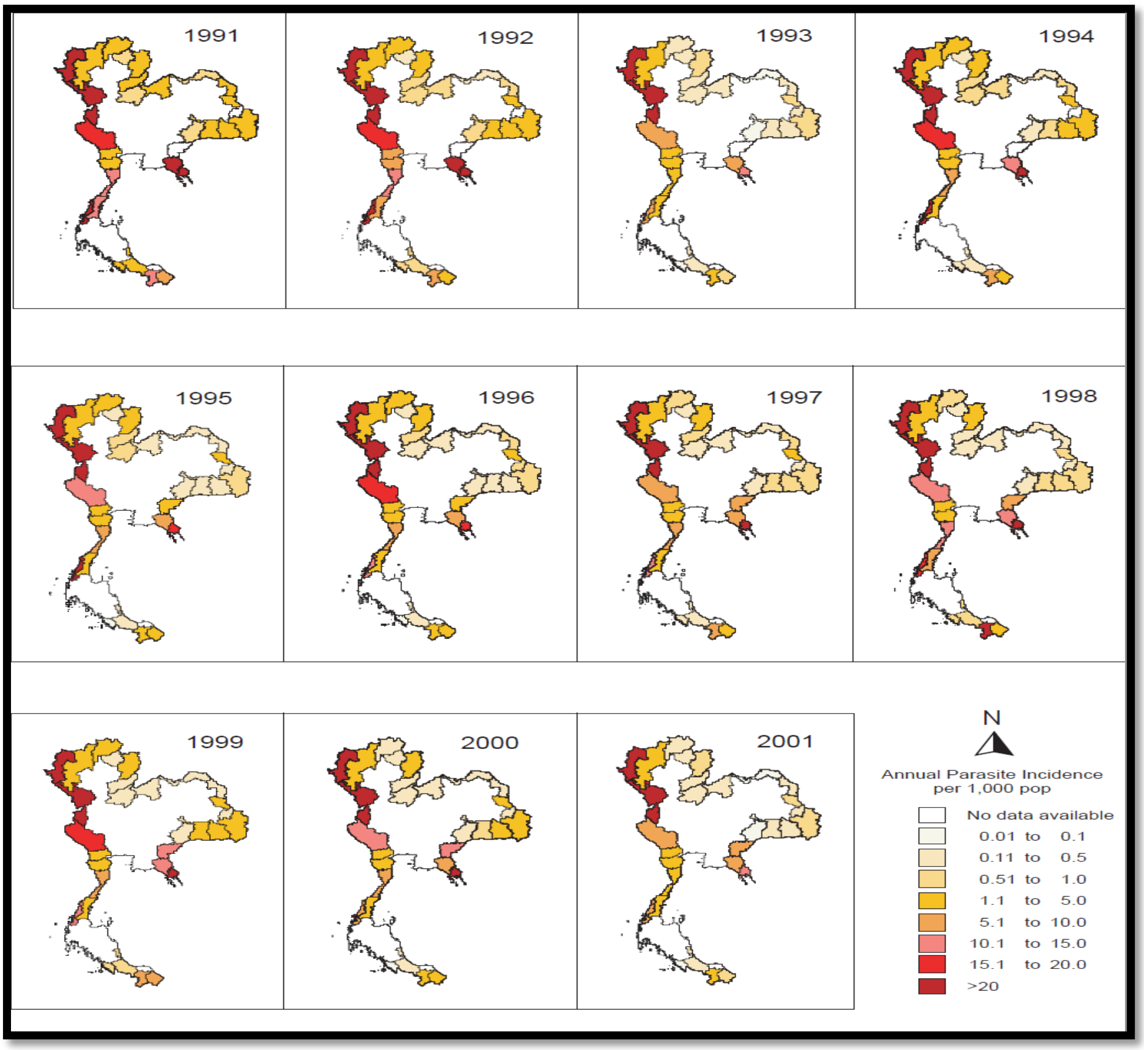

Figure 6.5 Trend of Malaria Incidence in Thai border provinces, in Thailand, 1991-2001[4]

In addition to incidence or prevalence of disease, the availability of health services can also be mapped as trend maps in order to evaluate the change in time. Using a Malawi geographic data on the location of antiretroviral therapy sites and the number of people per site for five periods, Kelly (2007) has applied such trend maps to keep track of access to antiretroviral therapy sites (see figure 6.6).

[4]Source: Konchom et al. 2003

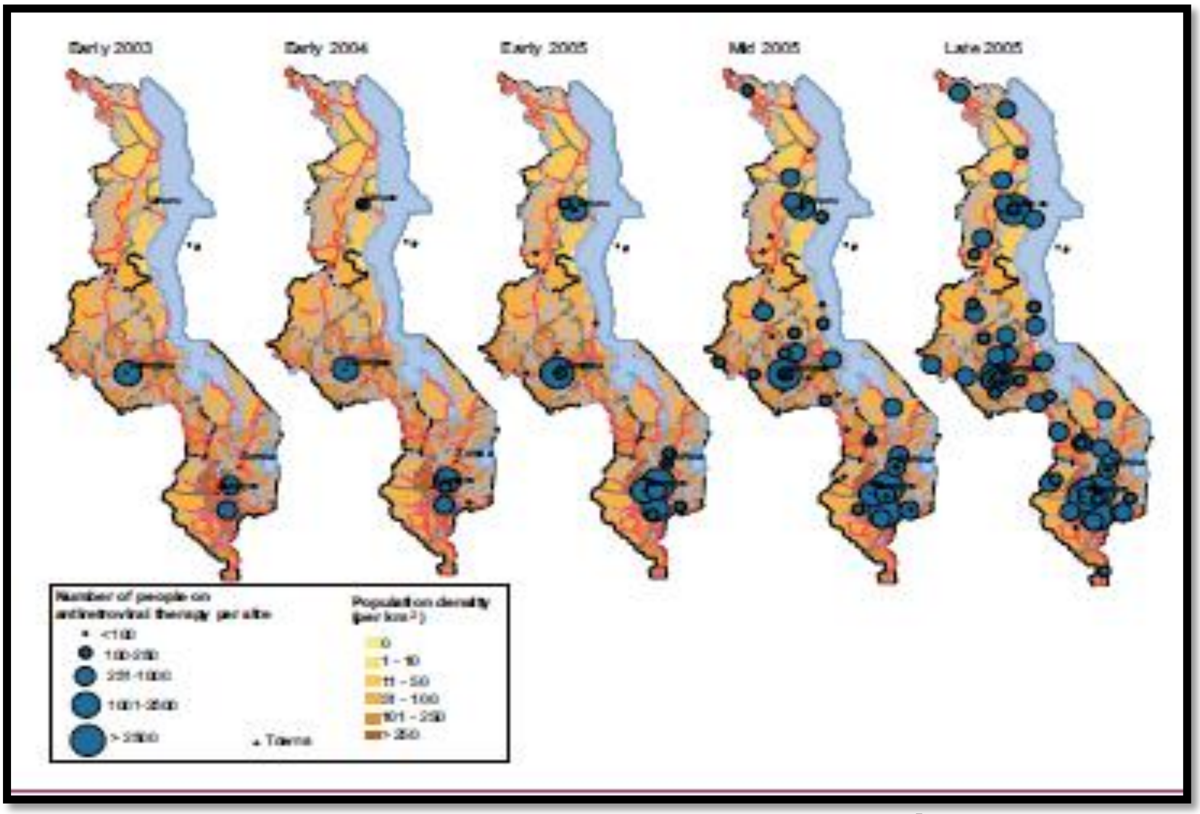

Figure 6.6 showing scaling up of antiretroviral therapy in Malawi 2003-2006[5]

The map in figure 6.6 shows how the number of antiretroviral therapy sites has increased in Malawi in three years and with it the number of people who use the service has also been increased. This map is designed as a combination of choropleth and graduate symbol mapping technique. With the shade of color value for population density , as light yellow for areas with no population and dark yellow for dense areas and a circle symbol with an increasing size for the number of people who get service on the therapy site , with the bigger circle mean more people and small circle less number of people.

So far, we have seen different ways of showing trend in a map. Trend can be shown as an animated map that changed the display of the data for as the year changes (figure 6.4). It can be presented as a serious of static map for different sequence of time period figure 6.5 and it is also possible to show trend maps which contain multivariate symbols using one or more mapping technique as it is shown in figure 6.6.

We can also show trend dynamics in a map with the addition of other graphics (eg. line charts). For example based on the Tigray data, we have generated a map in figure 6.7 to show the trend of malaria cases and number of bed nets distributed for the western zone of

[5] Source: Kelly ,2007

the Tigray region for the years 2006 to 2008. The trend shows in a line chart in combination with the base maps showing the geographic areas where the data is drawn from. The background color of the corresponding line chart is the same as the color of the specific area in the map. The Base map contains population distribution information for those districts to help us show how much of the population has been affected by malaria.

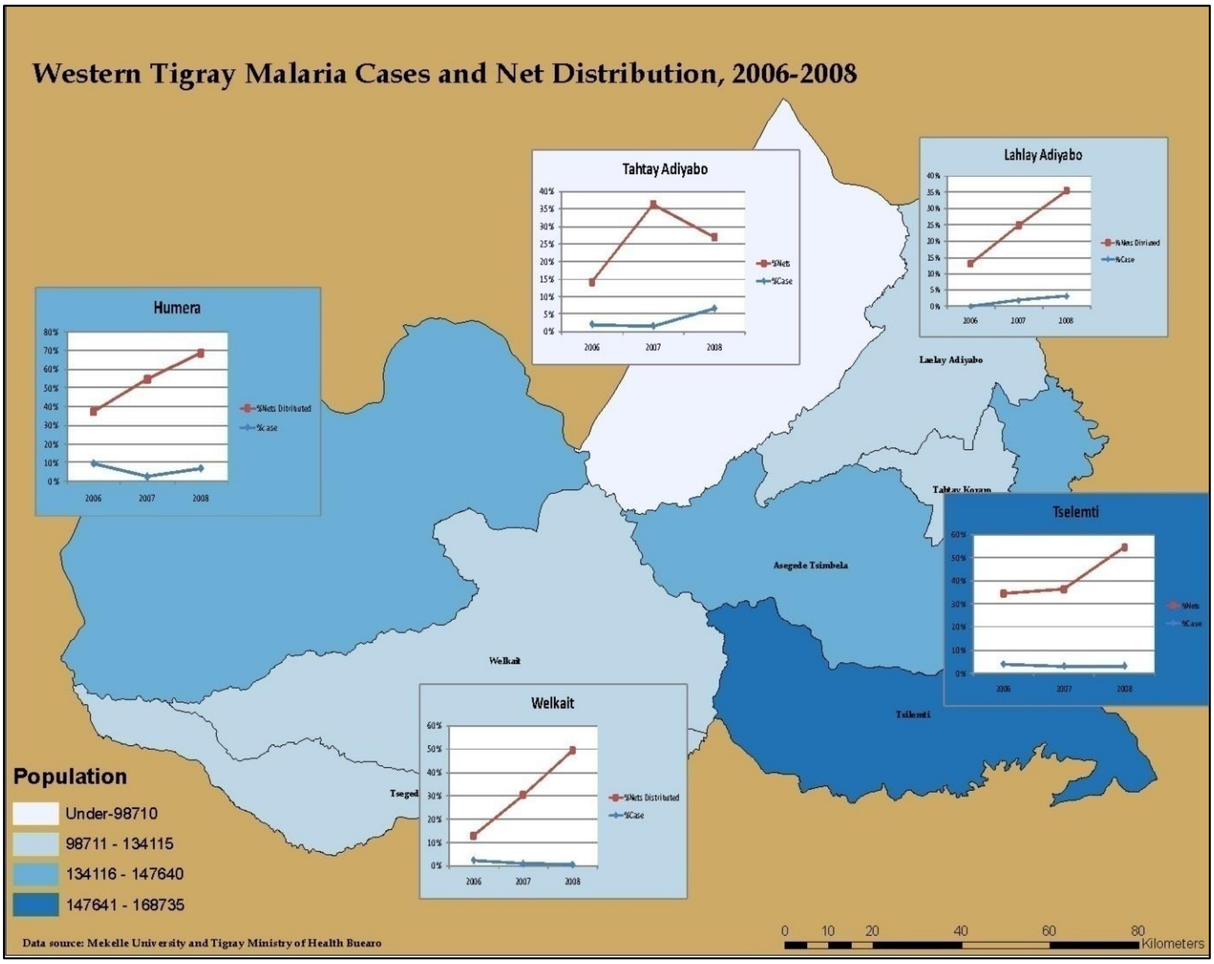

Figure 6.7 A choropleth map showing the population distribution on western Tigray and the trend of malaria incidence and net distribution for the years 2006 to 2008 in line graph.

The map can be utilized as a tool for malaria managers and public health administrators to evaluate a district level dynamics of the situation of malaria disease. For instance, it can be seen that even though the distribution of treated nets seems to improve over the whole period across the five districts, the incidence of malaria has only been getting worse in the Lahlay Adiyabo district over the period 2006 – 08. This may give a wakeup call to malaria managers and public health managers in the districts to evaluate their previous work and plan on how to improve it for the future.

In an attempt to show the trend of malaria incidence over the years 2007 and 2008, Figure 6.8 is dedicated to show how all the 36 districts in the region are doing in terms of comparing with previous year. which districts have improved and which ones are getting worse. Using the choropleth mapping technique and our standardized data which is number of patients in 2008 over the number of patients in 2007 gives us a clear view of the districts status in rank order.

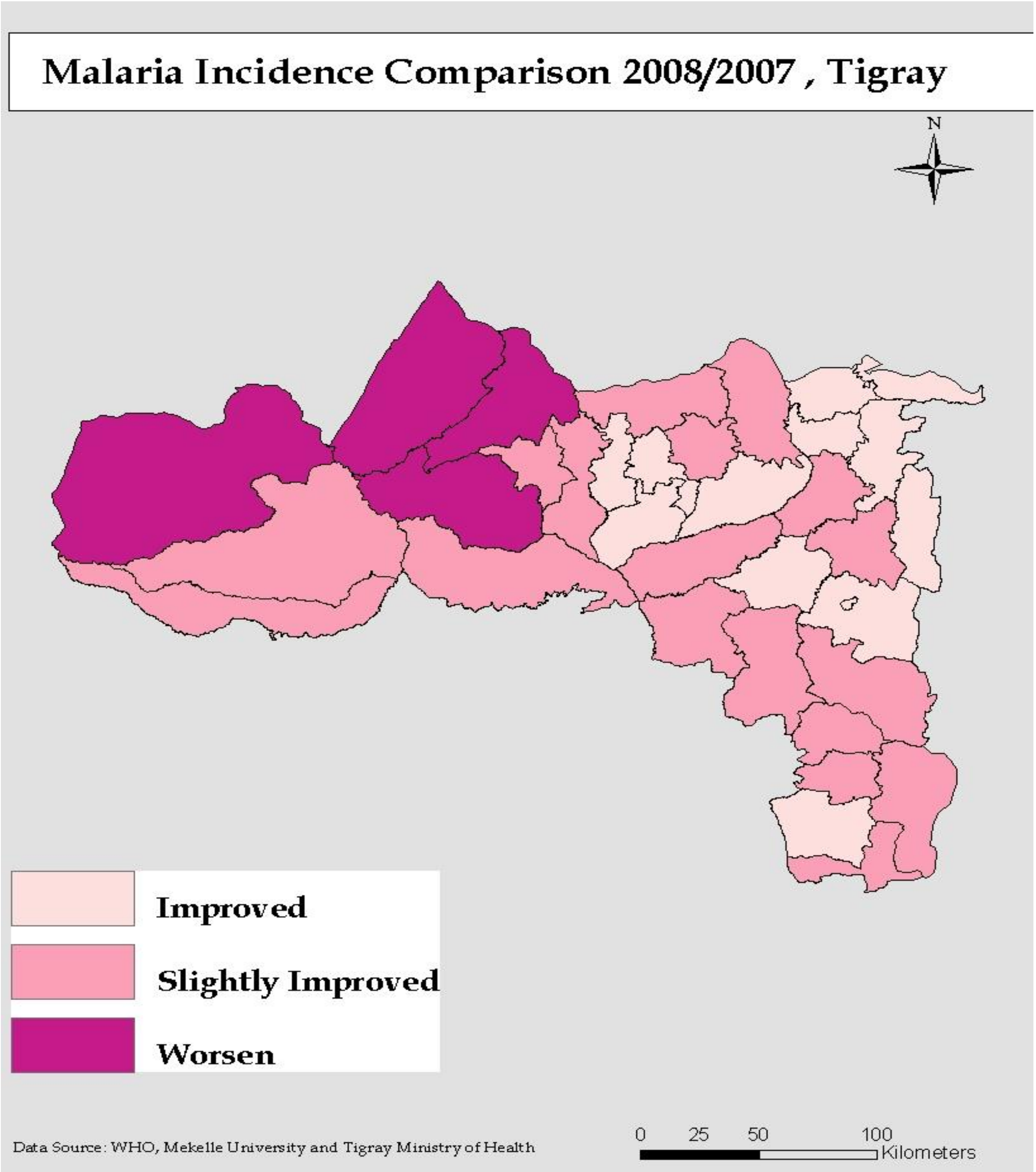

Figure 6.8 a choropleth map showing the trend of malaria incidence year 2007 to 2008 in Tigray region.

This map gives an overview of the districts progress to the regional health managers . As we can see from the map, it is only a small number of districts which are have improved well. Majority of the districts are showing a slight progress and some districts are still getting worsening. This can help the regional health managers to evaluate and monitor their work in malaria controlling program and it will inform for malaria experts and malaria researchers to do more investigation to answer to why some of the districts are still getting worst.

All of the trend maps shown above have demonstrated the role of GIS as monitoring and evaluation tool. The trend maps tell the public health managers and the malaria control program experts to evaluate their work whether they are on the right track to reach their objective and to monitor their progress.

6.3 Cause and effect maps

GIS provides a means for visualizing and analyzing data dependencies and inter relationships that would be more difficult to discover in tabular format. Specific diseases or public health resources can be mapped in relation to their surrounding environment, socio-economic conditions and social infrastructures. Such information when mapped together creates a powerful tool for monitoring and management of diseases and disease control programs. The underlying factors (environmental, social, behavioral) that, most likely, cause the incidence of a disease and/or an increase in the incidence of a diseases can be identified by the help of GIS mapping and analysis. By tracking the cause of a disease and the movement of contagions, health agencies can respond more effectively to the outbreaks of epidemics by identifying the relevant population at risk. The public health literature in general and malaria control programs researches in particular are rich in showing maps and graphs that have been generated with the purpose of trying to find out the possible cause of a specific incidence and with the purpose of evaluating the effects of a specific intervention in the control program.

In the first place interest in geographic disease mapping began with the recognition of maps as useful tools for illuminating potential ”causes” of disease (waller &Gotway, 2006). In 1866 DR. John Snow traced the cause of outbreak of cholera by mapping the location of drinking water pumps in relation to the homes of people who died in London (see Figure 6.9). He believed that cholera was transmitted through drinking water, but at the time, this theory was scrutinized with extreme skepticism. He succeeded in identifying the source of the epidemic which was a single contaminated water pump.

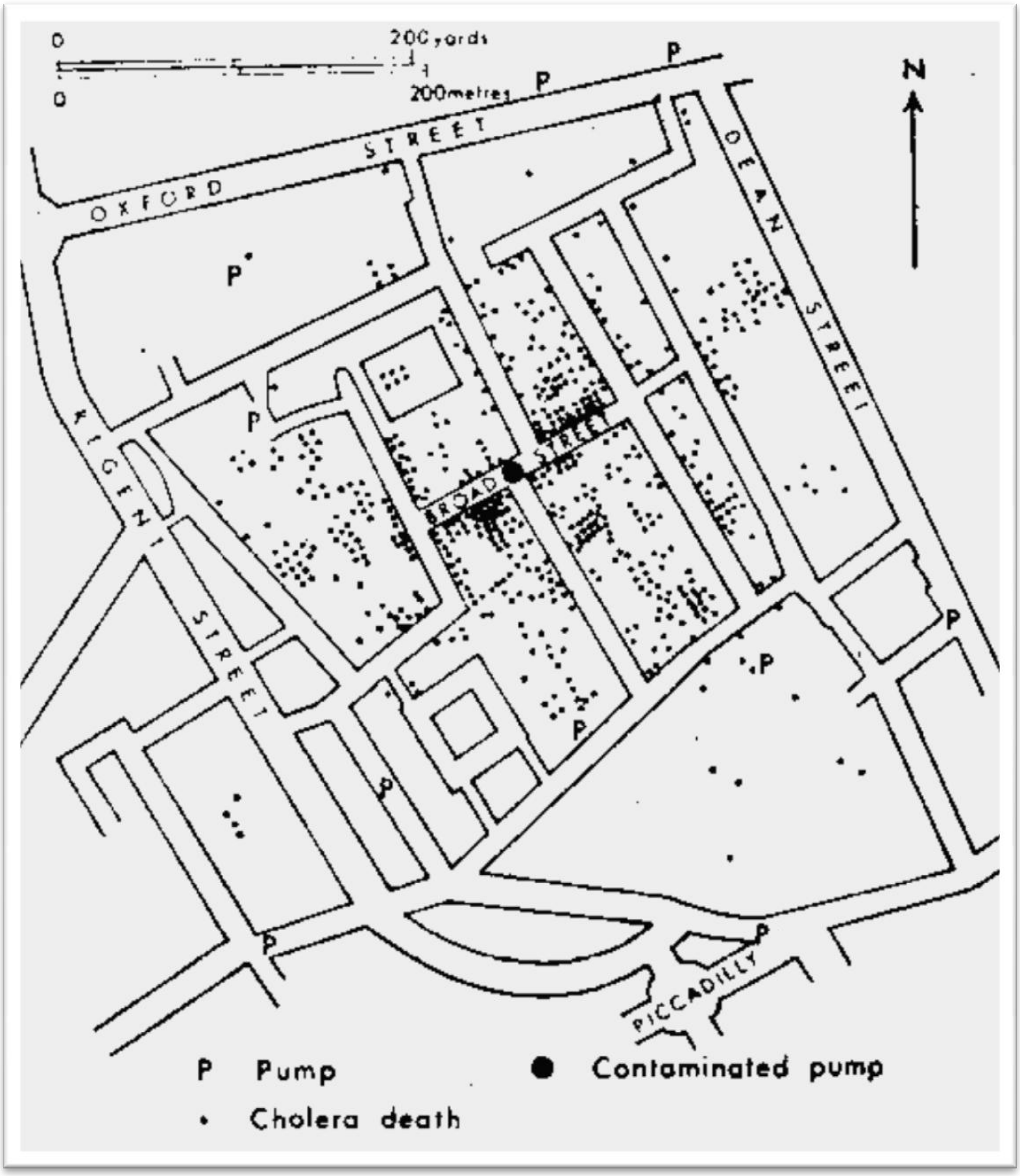

Figure 6.9 Dr.John Snow's dot density map of cholera cases in London, 1866[6]

Maps that try to assess the possible cause of malaria incidence and the effect of intervention are very crucial in malaria management program. In most developing countries malaria transmission is seasonal and depends on different factors such as topography, rainfall, latitude, water body, and temperature. Hence, creating maps with a combination of one or all of the above factors with the incidence of malaria is very important in identifying the

[6] Source: Cromley & McLafferty, 2002

exact cause of the malaria endemic and take proper precautionary measures. Various studies have utilized such mapping with the purpose of trying to find out the possible causes and effect of different factors that are associated with the incidence of malaria on specific areas. In the east Sepilk province of Papua New Guinea, a remote area where malaria is a major cause of morbidity and mortality, a study by (Myers et al. 2009) was designed to evaluate whether geographic parameters have effect on malaria infection. Village locations were mapped with distance to administrative centers, elevation, latitude and longitude information and overlaid with malaria prevalence data Figure 6.10. The study found out that malaria is significantly associated with lower elevation and greater distance from administrative centers.

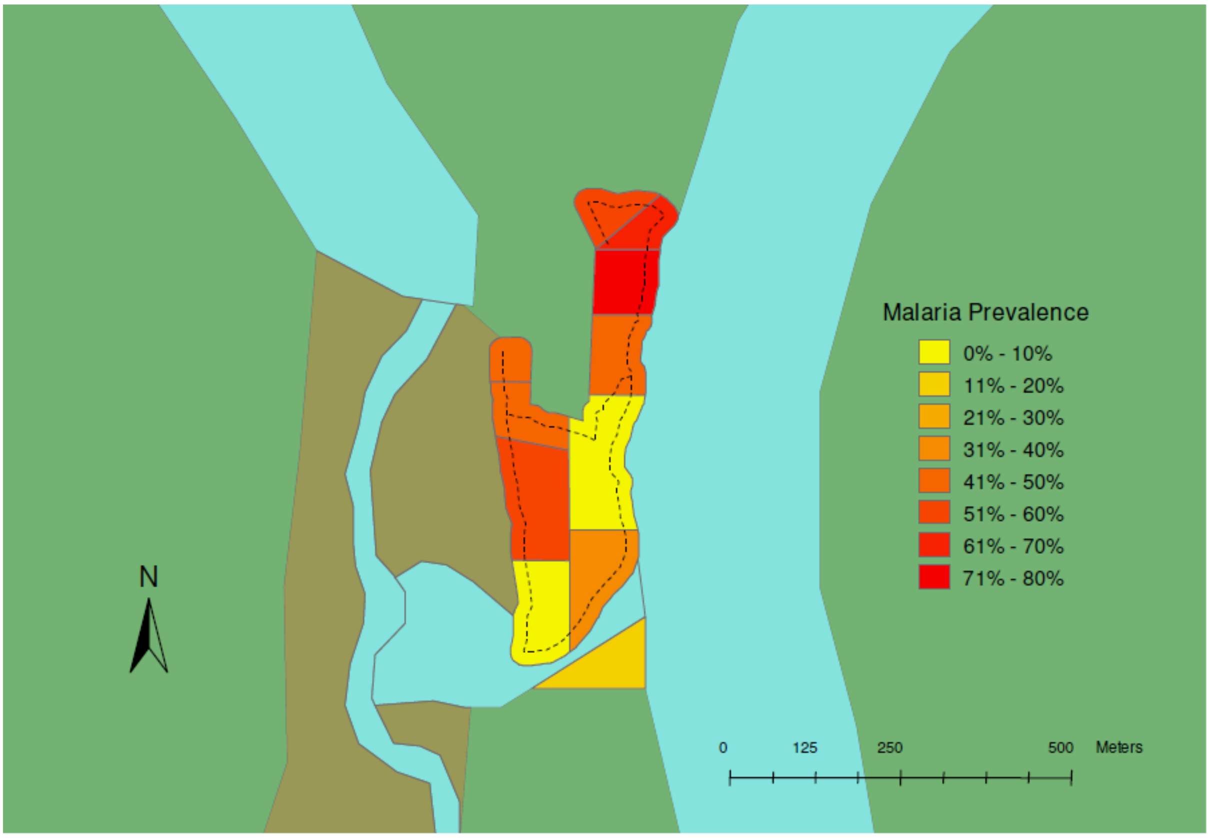

Figure 6.10 Prevalence map for malaria infection in Oum villages. [7]

[7] Zones with in the village are color coded from low(yellow) to high(red) prevalence. Other geographic features : river, dry riverbed, and jungle are colored blue,brown and green respectively. Main footpaths are represented by dotted lines.

Using data from the Tigray region of Ethiopia, a study by Ghebreyesus et al., (1999) has tried to assess the effect of micro-dams construction on incidence of malaria in children living near those dams. Four quarterly cycles of malaria incidence surveys have been collected on about 7000 children under 10 years old which resides within 3 km of micro-dams as well as in control villages that are 8-10 km away from the dams. The result shows that micro-dams close to villages have the potential to increase the incidence of malaria substantially among children living nearby.

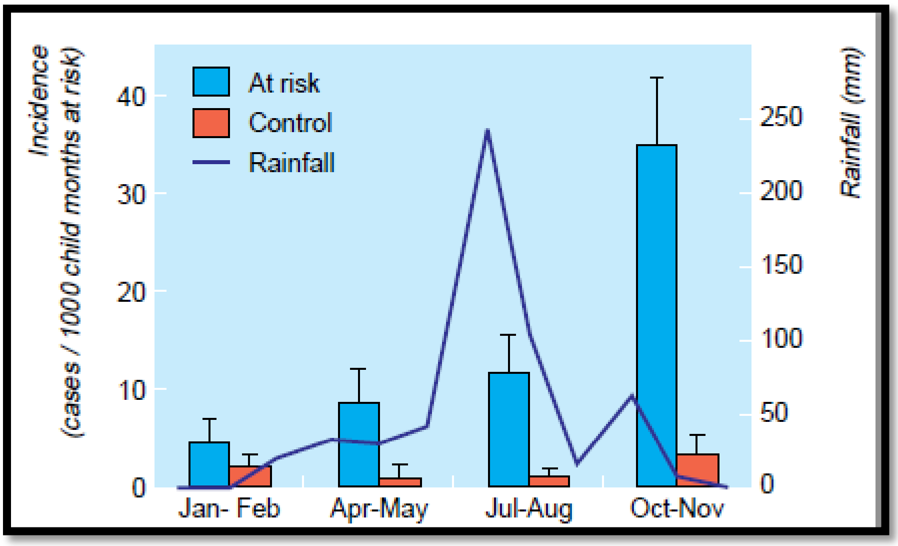

Figure 6.11 incidence of malaria (with 96% confidence intervals) among children under 10 years in the Highlands of Ethiopia in at risk communities (close to dams) and control communities (away from dams) during 1997.

Using the available data on possible factors associated with the incidence of malaria, we tried to show two more example of maps that are useful in malaria management to identify possible cause of malaria incidences (figure 6.12) and maps that can help evaluating the effect of intervention coverage (Figure 6.13). Figure 6.12 is designed to assess the impact of dams in malaria incidence . Based on the map, we tried to investigate if there is a realtively high mlaria cases with in 10 km buffer zone in each dams than in areas where no dams exist. As it shows in figure 6.12 , malaria is every were in the region , but the map does not show high malaria incidence near the dam area.

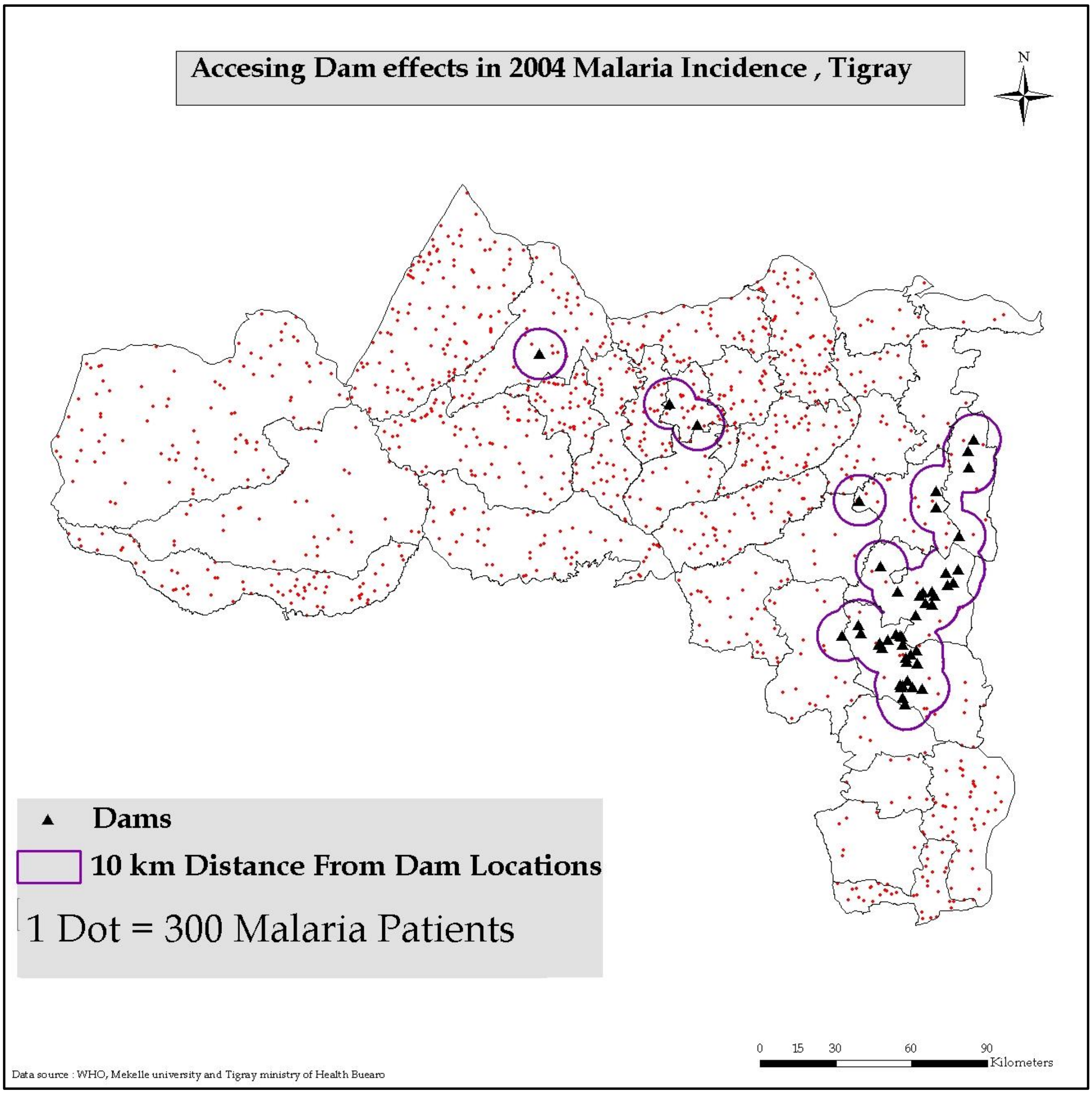

Figure 6.12 A dot density malaria incidence map with geographic position of dams with in a 10 km catchments area.

The data used to create the dot density map is a total malaria patient for each district which is appropriate for the mapping technique used(Dot mapping technique) [8]. The dots don't represent the specific location of a single patient. Rather the density of the dots show how high or small the number of patients within a given geographic area is. One dot represents 300 malaria patients. Extreme caution has been exercised in choosing the dot values and the size of the dots. Based on the general guidelines we discussed in section 3.6.6, we chose a dot value that results four dots being placed in the area that has the least mapped quantity

[8] For details, see discussions under section 4.

and with further experimentation, we have chosen the dot sizes which gives a better overall impression.

Using district level data on the distribution of insecticide treated bed nets from 2006 - 2008, Figure 6.13 shows the impact of such intervention coverage during a given year on malaria health outcome of the immediate subsequent year. As insecticide treated nets (ITNs) are a key intervention to control malaria, the map shows the positive effect of its distribution in minimizing malaria incidences in each districts. Furthermore, the maps show that in areas where the intervention coverage is relatively low, malaria incidence gets worse.

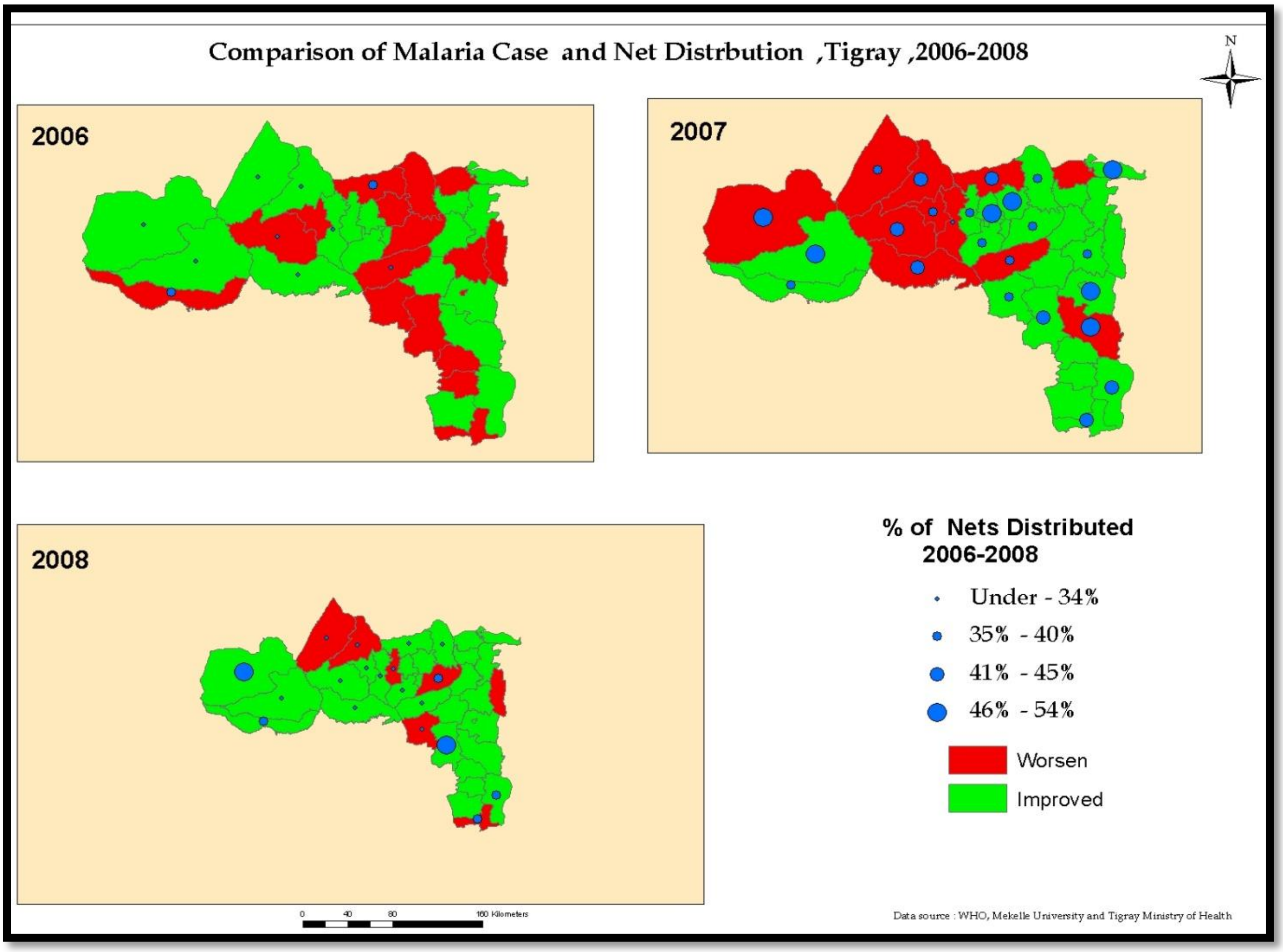

Figure 6.13 The effects of distribution of insecticide treated nets for the year 2006-2008 on malaria incidence

Such a map is a bi-variant map designed using choropleth mapping technique and graduate symbol mapping technique. The data chosen to be portrayed by the choropleth mapping technique is the qualitative data which shows worsened or improved areas with the color of green for the improved ones and red for those which gets worse. The standardized data percent of insecticide nets distribution for each year has represented using graduate symbols technique that represents difference using the dot sizes. As we can see from the map, the net distribution in 2006 was very small. Consequently, in 2007, most of the districts show as worsening of the malaria incidences. This map can provide important information for the malaria managers in order to evaluate their net distribution intervention in accordance with the incidence of malaria.

6.4 Incidence Maps

Maps in this category are intended to show the geographic distribution of malaria incidence in the region (figures 6.14 and 6.15). A map showing the incidence rate of a disease as its name implies shows the number of new cases per population in a given time period. Incidence maps are common in disease mapping, for example there are Global incidence maps for rabies, heartworm, cancer, lyme, HIV/AIDS and many more diseases.

Our category of incidence maps, includes maps which show the geographic distribution of malaria incidence in relation to its population and those maps which aim to answer question like, where malaria disease is most prevalent? Which population and geographic areas are most in need of prevention programs and treatment? How much of the malaria patients did get treatment? How does its severity show compared to what has expected (Anomaly detection)?

Figure 4.10 shows malaria incidence rate in the region. The map is designed using choropleth mapping technique and the incidence data were standardized as rates rather than total. Rates give a better representation of the data because of the varying size of the districts. Color value has been used to show the quantity difference, dark brown showing areas with high malaria incidence rate and light yellow for low incidence rates.

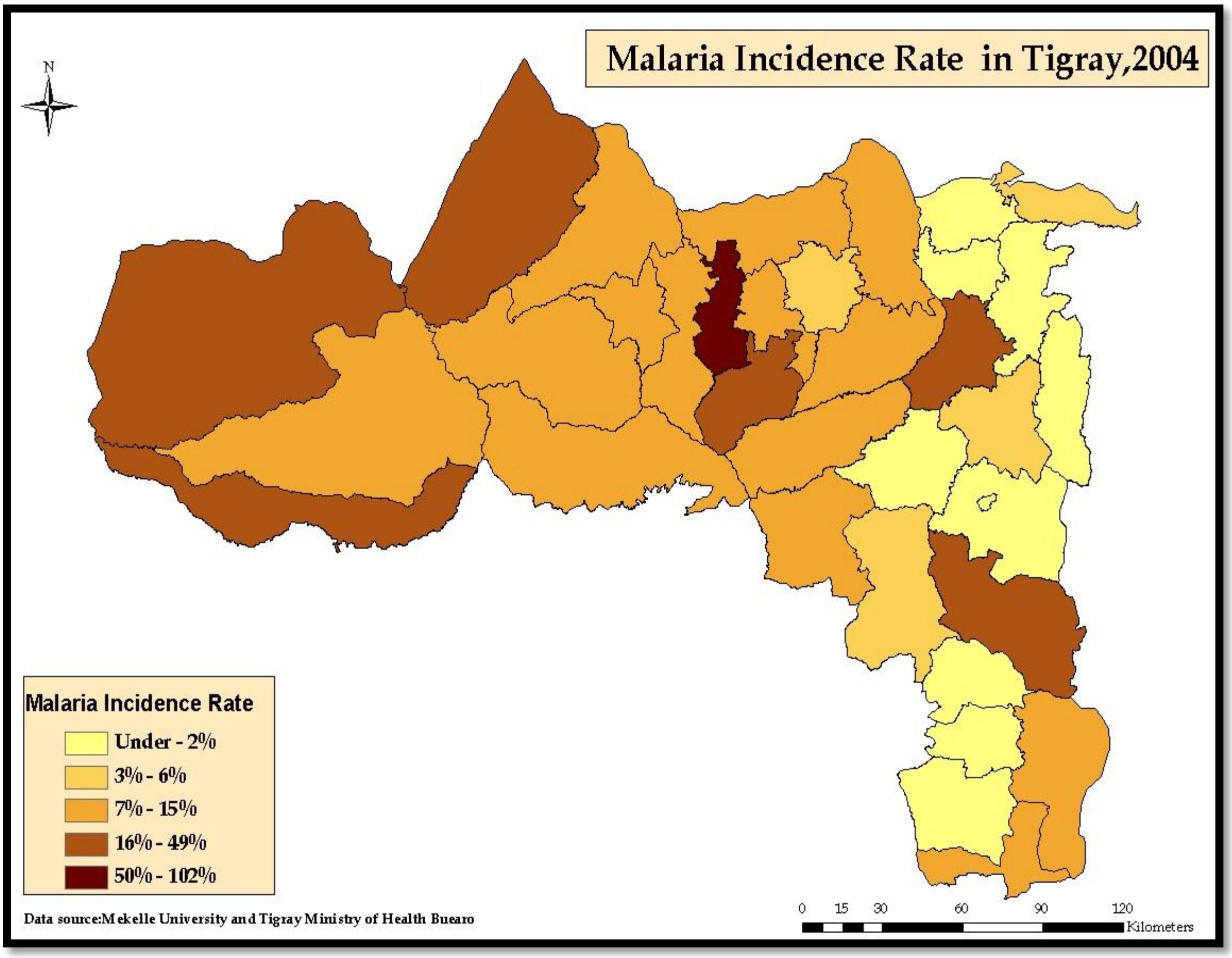

Figure 6.14 Malaria incidence rate in Tigray region, data 2004

The map in figure 4.10 can provide crucial information to malaria control program managers at district level as well as at regional level to identify areas which are endemic to malaria and those which are free of malaria. This can help to identify the size of malaria problems in the region and for these endemic areas an early warning system can be given. The percentage on the map shows more than 100, this is because the number of malaria patients data on one of the districts in the region on 2004 shows more than the total number of population on the district. Our guess is some people in the district might have been sick twice in that particular year and registered twice in the health information system.

Figure 6.15 is created as a combination of choropleth mapping technique and a point based symbol (pie chart). The choropleth map is represented with standardized data malaria patients per 10,000 people and shaded using colour value. The lighter colors shows areas with low malaria incidence and the darker colour high incidence. The pie chart shows relationship between total number of patients treated by CHW ,women and children less than 6 years old . Colour hue has been taken in order to show the kind difference which are red for male, green for female and yellow for children less than five year. The pie chart size varies as the total number of patients treated varies for each district.

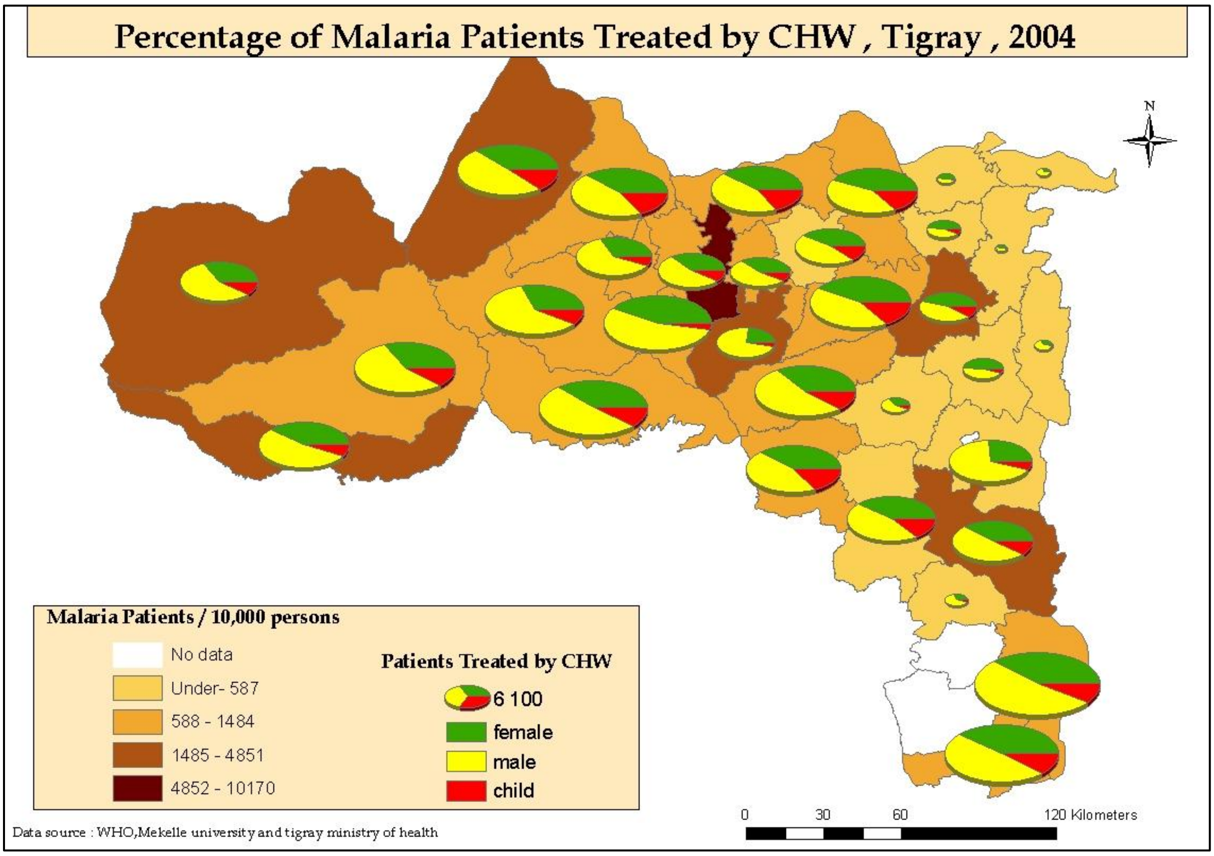

Figure 6.15 Malaria patients treated by community health workers in Tigray region, 2004

This map can help malaria managers to monitor and evaluate the work of the community health workers.

In figure 6.16 we tried to show the occurrence of malaria incidence in relation to what was expected for the year 2008 . This map is designed based on anomaly detection formula given to us by the malaria experts who gave us feedback on the maps designed in this study.

$$\text{Anomaly of of } X_i = \left(\frac{X_i - \text{Mean for all the years}}{\text{Standard Devation of the years}}\right)$$

X_i=Malaria incidence Value for each year

Those maps can provide the malaria managers and malaria researchers to identify areas with more malaria incidence than expected and based on the information research can be done on those areas to find the cause.

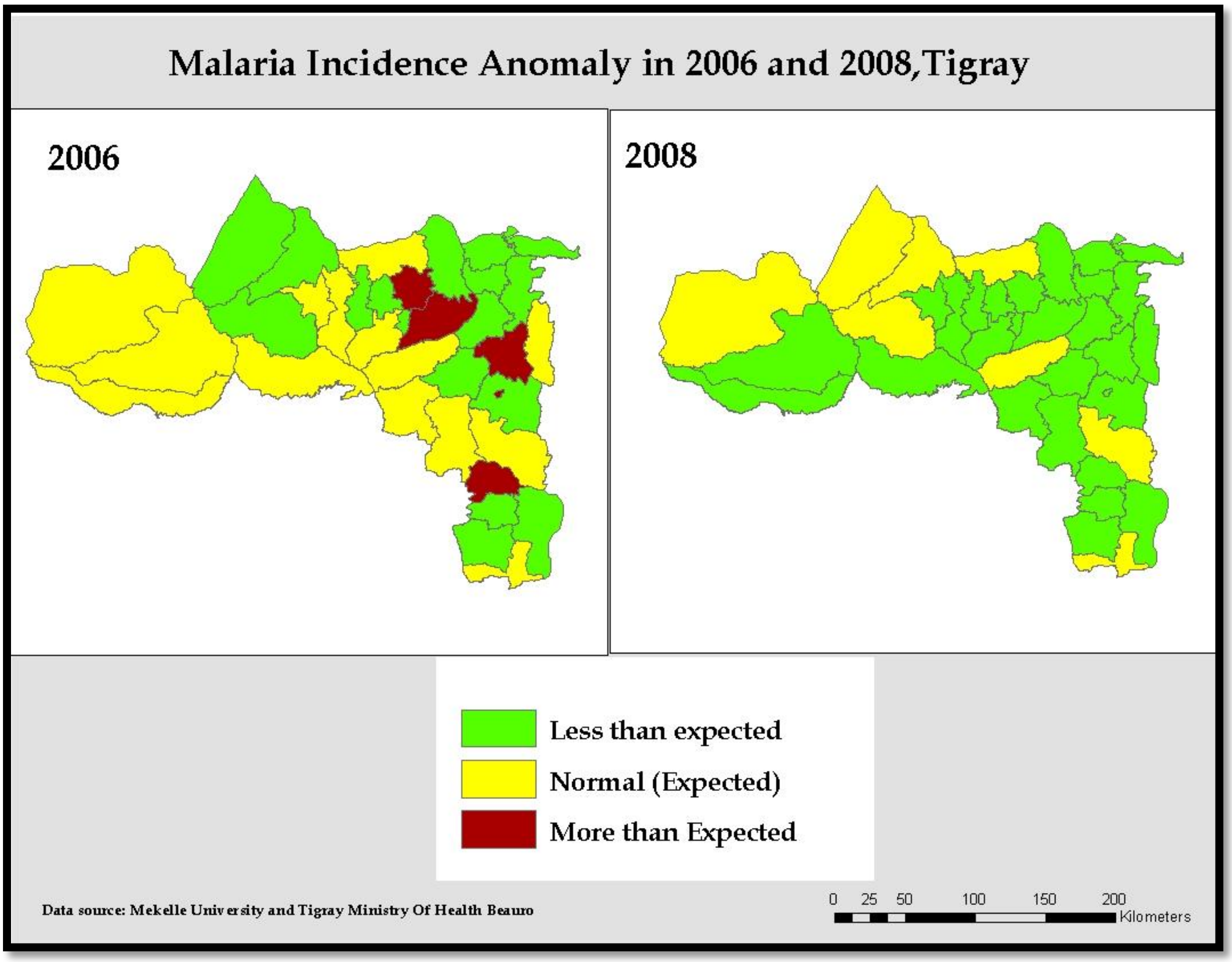

Figure 6.16 Malaria incidence anomally in Tigray region for the year 2008.

7. Putting all Together

7.1 Critiques and evaluation of the maps

Step five, which is the final step in the map design communication model adopted in this study, requires to determine whether the user find the map useful and informative. Ideally this step involves participation of the map's intended audience (in our case, the malaria experts, the public health administrators and the general public) in order to evaluate its effectiveness and to incorporate the users feedback in to the final design of the map. As we stated in section 3.4.5, any map maker should also evaluate and criticize his/her own maps before finishing the map design. Evaluating our maps will help us in determining whether the users will find the map suitable, interesting, confusing, boring or informative. Because of time constraint we only get feedback from two malaria experts on the initial design of the maps presented in chapter 4 as an example of useful types of maps for malaria management.

In this chapter we will present the "Map makeovers" we did on the maps presented in chapter 4 as an example of types of useful maps for malaria management designed based on the Tigray data by evaluating the maps, analyzing their design, and making improvements based on the comments from the two malaria experts and based on the knowledge we gained in map design principles from chapter two. Note that, in the makeovers that follow, the reader may still find problems. Not all cartographers will agree on all aspects of design (A.Tyler 2010). There is no perfect map; we just tried to make the best map possible given our skill, data, equipment and the feedback we get from one group of the intended users.

Map Makeover							
Health Service Maps		**Trend Maps**		**Cause and Effect Maps**		**Incidence Maps**	
Before	***After***	***Before***	***After***	***Before***	***After***	***Before***	***After***
Figure 7.1A	Figure 7.1B Figure 7.1C	Figure 7.4A	Figure7.4A	Figure 7.6A	Figure 7.6B	Figure 7.3A	Figure 7.3B
Figure 7.2A	Figure 7.2B	Figure 7.6A	Figure 7.6B	Figure 7.6B			

Table 7.1 List of Maps to redesigned

MAKEOVER 1

Purpose: Figure 7.1A was designed with three intended purposes. The first purpose was to see how the health institutions are distributed in relation to the population density; the second one was to assess the malaria situation in relation to the distribution of health institution and the third one to see how much of the population are out of the catchment area of any health institution .

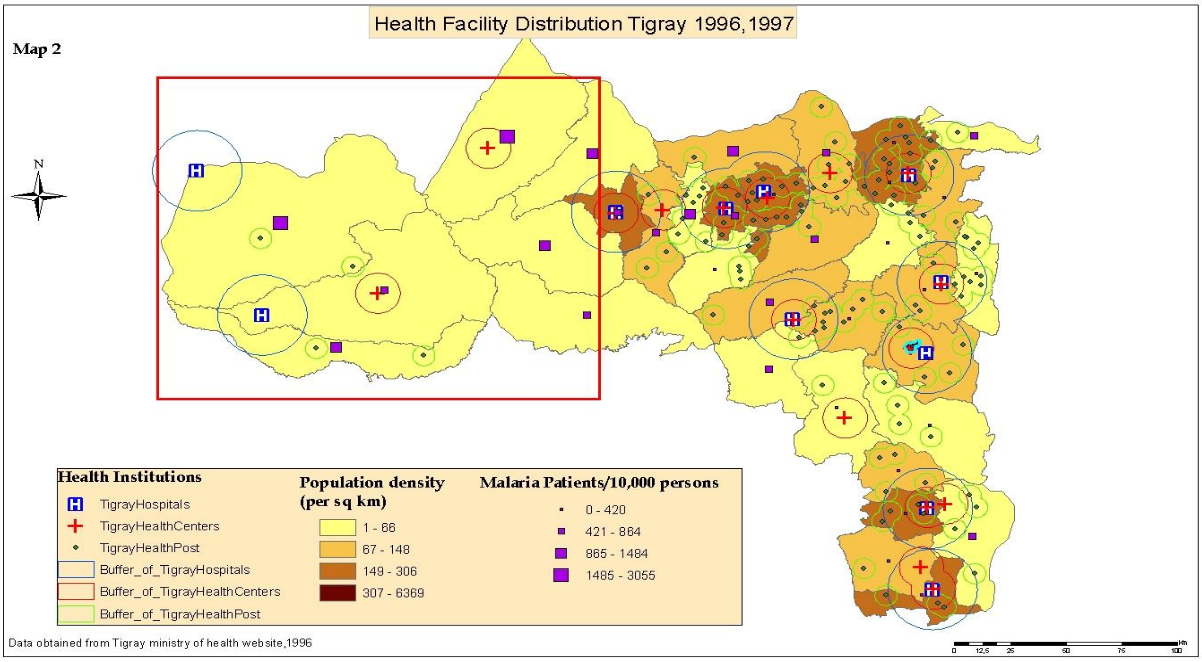

Figure 7.1A Distribution of health institutions in Tigray region in relation to population density and malaria cases /10,000 population.

Experts comment:

a) *Do the malaria patients/10000 people take into account the coverage of health clinics etc? If the population is evenly distributed in the region (which it would not be) you could calculate the area covered by health clinics (A1).*

*If you assume that all patients came from the buffer zone (which would be a natural way to read the map) you would than calculate A1 * malaria cases/(number of people in A1). If you have a gridded population map it would probably be more correct.*

b) If the buffer zones do no reflect the usage of health services it could be misleading to show them as are now.

c) Would it be needed to show the population density, or would it be enough to show the relative number of malaria cases (maybe as color). If you would like to show the how many people have access to health services in each district we think it would be better with a higher population resolution. To help the viewer it could be an idea to relate the number of malaria patients to the population ".

To summarize the their comments , the experts did not think that it was appropriate to show the buffer zones (catchment areas) of the health institutions unless it shows the number of patients with in those catchment areas and compare to the number of patients out side the catchment area of the health institutions. The other comment they give is that if this map is intending to show the malaria situation in the region, then it should be compared to total population than to population density. Most importantly the questions they raised clearly suggest that the map was not clear in conveying its intended message.

Critiques based on design principles

The title of the map was not explanatory enough to the purpose of the map. As the purpose of the map was to show the distribution of the health institutions in relation to population and malaria distribution in the region, but the title only informs about the distribution of health institutions . The size of the title was small. As we explained in section 2.4.4 titles are the important elements of the map , the size of the title should be two or three times the size of all the other map elements on the map. The map has a large north arrow that serves almost no purpose compared to the title and the legend. Most map readers scan the entire map starting from the upper left to lower right (section 2.2.4) . So that the important map elements that we need the reader to see first should be positioned in the upper left part of the map. In the previous map figure 7.1A the north arrow was placed in the upper left which is not appropriate. The most important critique for this map is even though often it is necessary to show more than one variable in one map, but it is better to develop separate maps if possible to minimize complexity and to make the map easy to understand. This map contains too much information to understand at once. Most importantly as we saw from the experts comments, this map does not meet its intended purpose

Makeover : The first thing we considered on doing the makeover was trying to make the map easier to understand with having a few variables. On redesigning the "before" map, we end up having two maps with two different purposes figure 7.1B and figure 7.1C.

The purpose of figure 7.1B is to find out how the health institutions are distributed in the region in relation to the population distribution and figure 7.1C is designed with the purpose of trying to show how much of the population are out of the catchment area of any health institution . As we read the comments of the malaria experts, it would be more informative and appropriate to show the purpose of figure 7.1 C with the number of population which resides within and without these catchment areas of the health institution, but the population data we have is aggregated data at district level. We don't have population census data or as the experts call it gridded population, because of this limitation we were not able to calculate the population inside the catchment areas. However, with the addition of the villages in figure 7.1C, though we don't exactly know how much population lives in each village it is still possible to anticipate how much of the population lives far from any health care service.

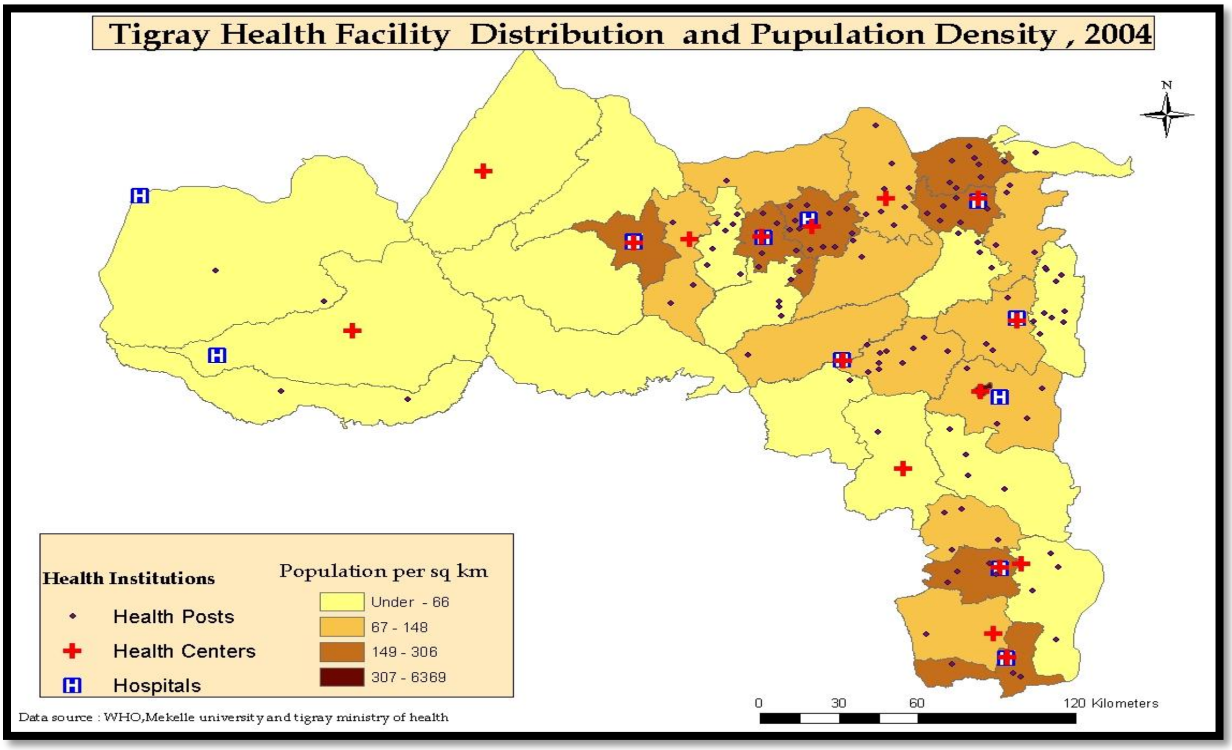

Figure 7.1B choropleth map showing the distribution of health facilities(hospitals, Health centers, health posts) in Tigray region in combination with population density per km^2

The layout of the map elements has been rearranged. An explanatory title has been added to both maps and the north arrow has moved to the right side of the map. We also increased the font size of the title in order to make it more visible.

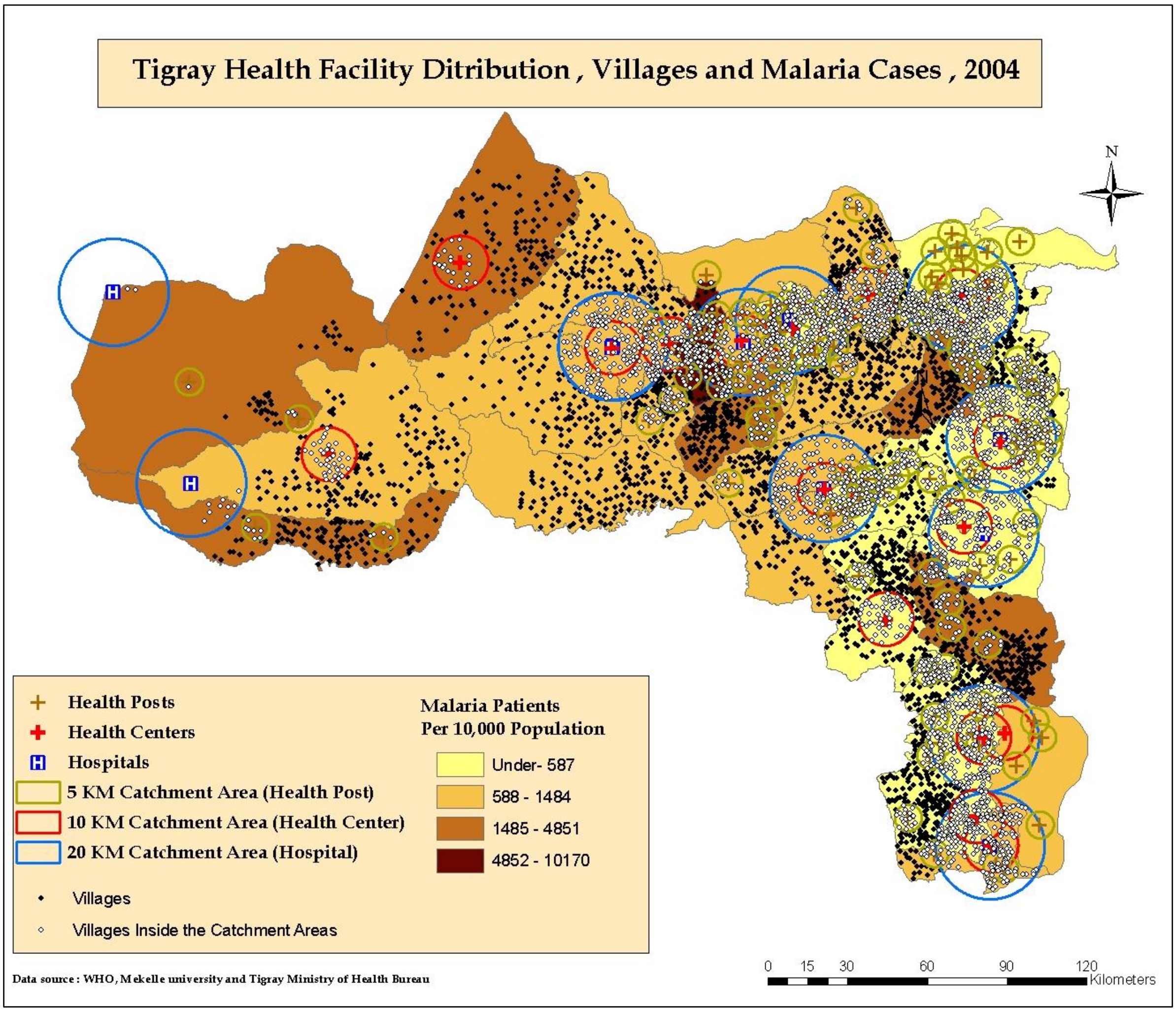

Figure 7.1C Choropleth map showing distribution of health facilities, and malaria patients per 10,000 populations.

MAKEOVER 2

The purpose we designed for figure 7.2A was in order to see how much percent of the population lives with in 10 kilometre distance from any health facility. This information is accessed from annual health profile report for Tigary region for the year 2004.

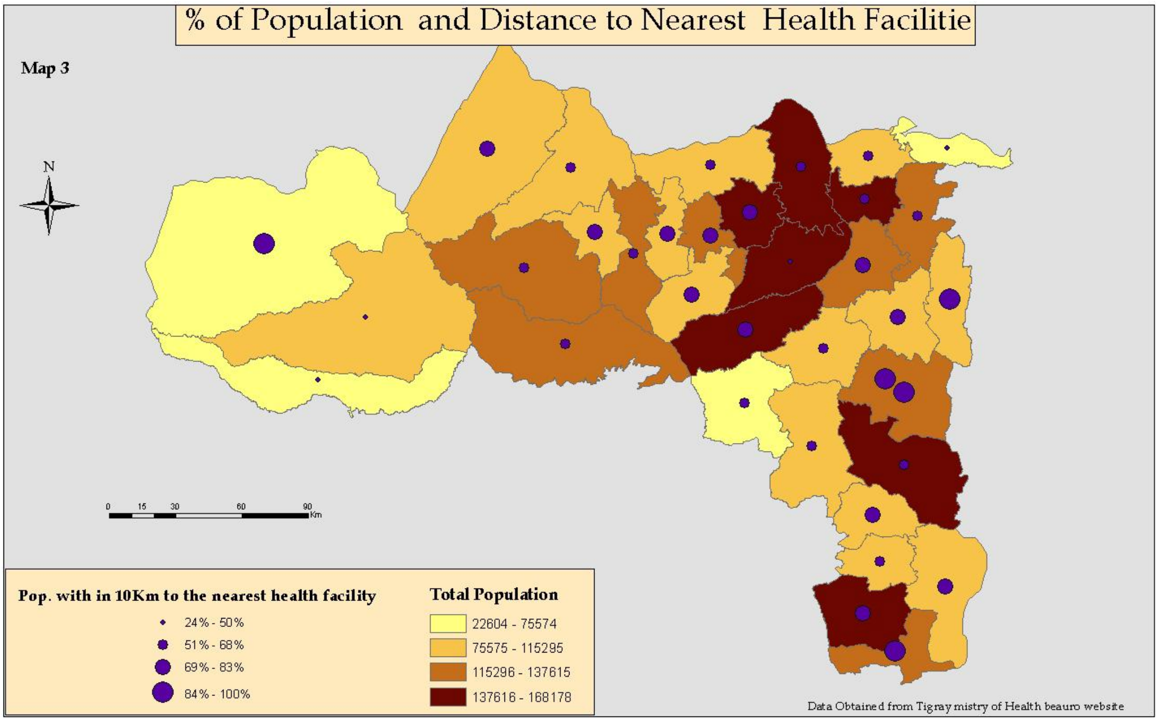

Figure 7.2 A Population distribution with in 10 kilo-meter distance from any health facility

Experts' comment: "*We like this one. But, why 10 kilo meters? Would it not make more sense to continue using the buffers from figure 7.1A ? Label would then be population within the catchment area of a health service. It makes sense to show the total population in this figure. Purple on dark brown becomes a bit invisible*".

To summarize the experts' comments, they said that figure 7.2A was useful and meets its intended purpose, but it would be good also to show the number of population inside those catchment areas we created in figure 7.1A. The other thing that the experts commented on was on the choice of colour. They said that the graduate symbol purple colour is invisible when it is on dark brown.

Critiques based on the design principles: The worst error on this map is using a total value for enumeration areas which vary widely in size (section 3.4). The second error is the lay out position of the scale and the north arrow. As we explained for the critiques of figure 7.1A scale and north arrow are less important compared to title and legend ,so they should be placed on the left side of the map.

Makeover - Figure 7.2B. First the data were manipulated to give information as population per 10,000 than as total numbers for the choropleth mapping technique. The scale and the north arrow designed to be noticeable but not that much noticeable and went to the left side of the map. Based on the experts comments we changed the color of the map with the help of color brewer . The four shades went from black for the highest to white for the lowest. The graduate symbol color went from purple to red. Now red on dark black looks great and more visible.

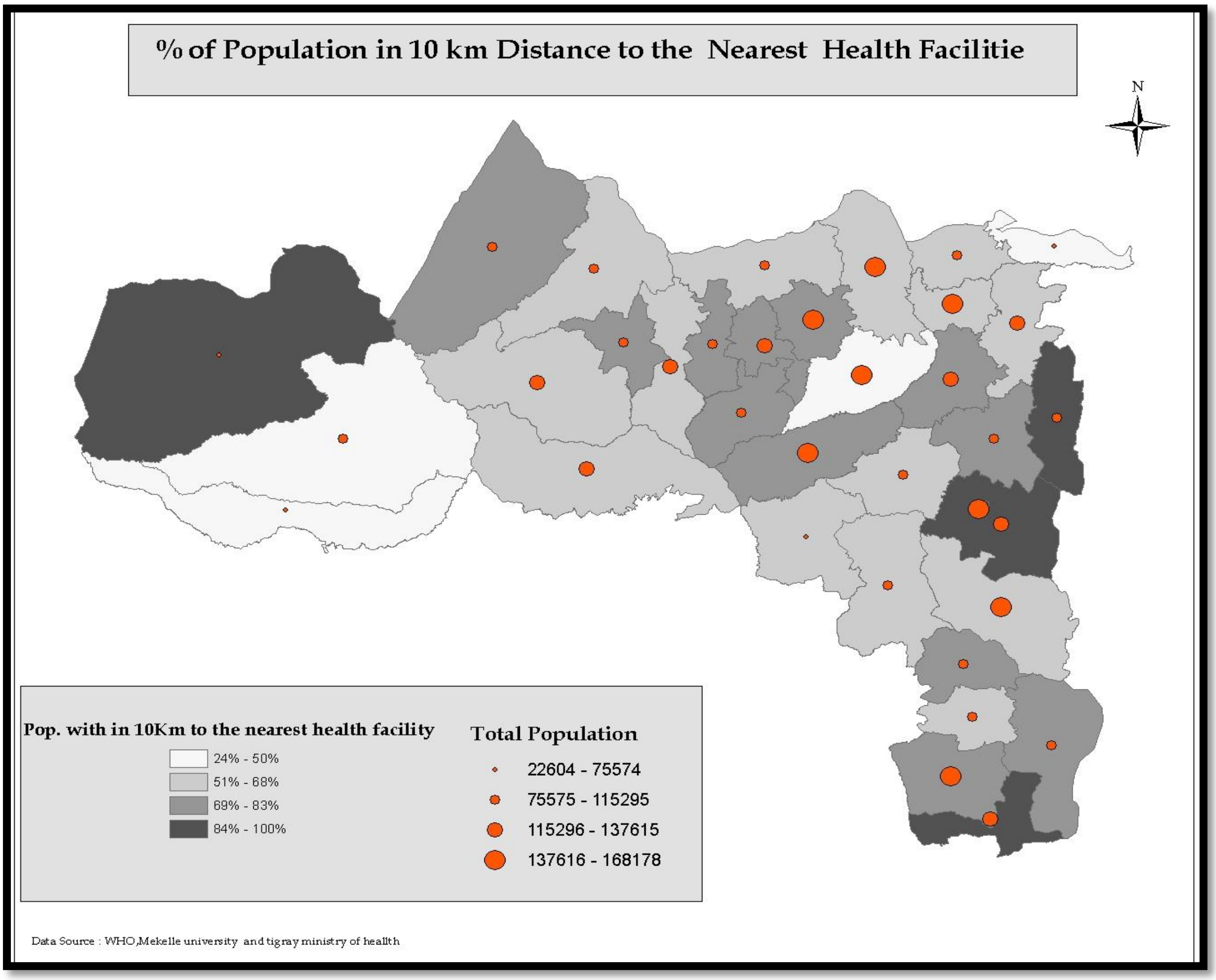

Figure 7.2B Population distribution with in 10 killo meter distance from any health facility

MAKEOVER 3

Purpose: Figure 7.3A was designed in order to show how much of the malaria patients were treated by community health workers and how much of them were male, female and children under five year.

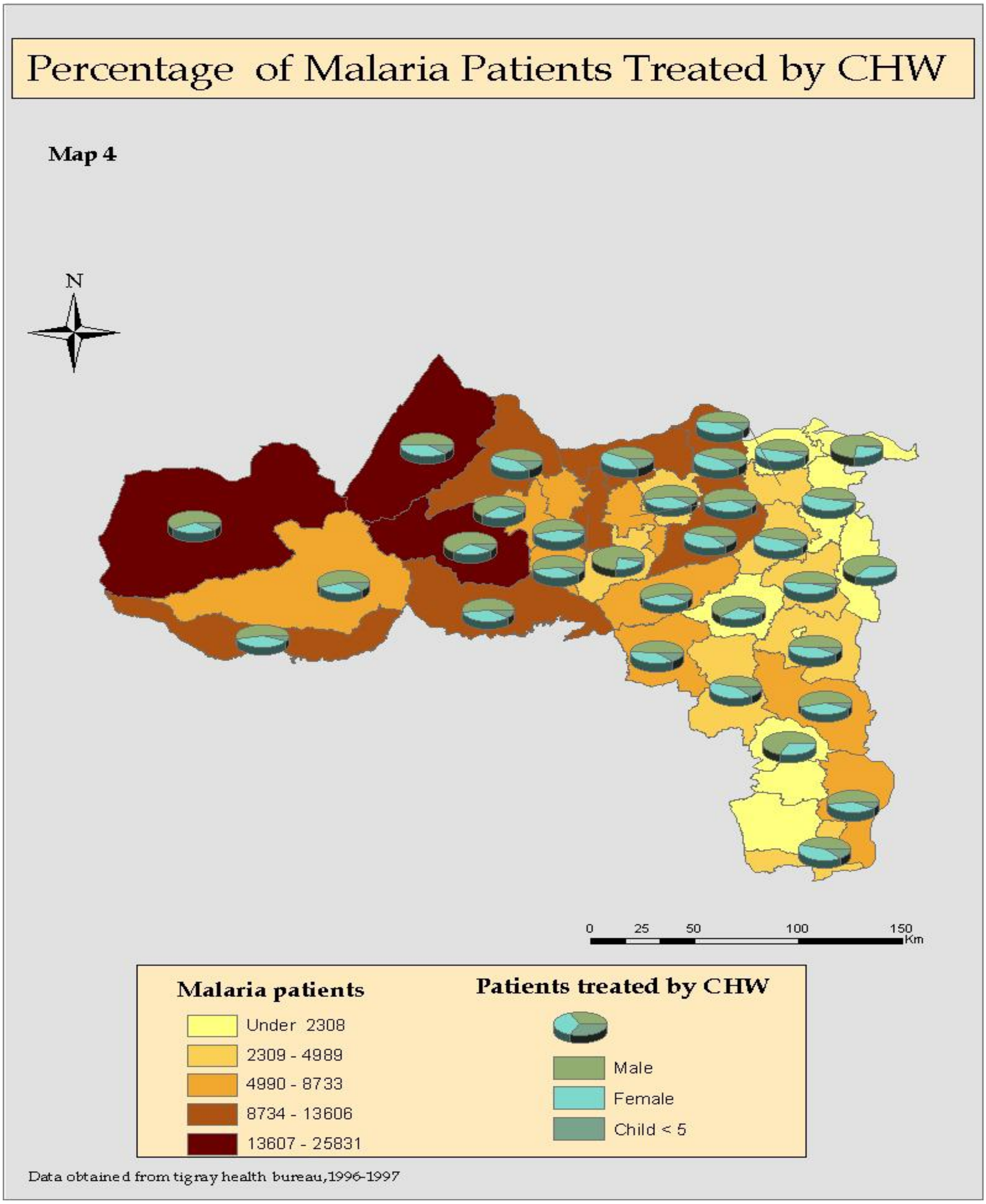

Figure 7.3A Number of malaria patients treated by CHW (community health workers) by gender and age group and the actual number of malaria patients for each woreda.

Experts' comment: *This one does provide useful information. A small thing would be to make sure the colors in the pie charts are not too similar. Where you don't have information on patients treated by CHW don't display number of malaria cases either.*

Critiques based on the design principles: The data used for the enumeration areas were un standardized data which is not appropriate for choropleth mapping technique . The experts also commented on this, on our telephone conversation with them , they said it is always good to use the data in somehow standardized than total. The size of the pie chart should vary, since the total number of patients treated by CHW varies from one district to the other .The colors on the pie chart shows a bit of order and also too similar, which makes it difficult to identify the parts easily. The alignment of the map elements is not right.

Makeover - Figure 7.3B: The data were manipulated to give information as malaria cases per 10,000 population rather than as total numbers. Per 10, 000 population gives a better representation of the malaria data because of the widely varying size of the districts and the population. Color hue has been used to show the kind difference as male, female and child with the color red, green and blue. . Based on the experts comments the pie chart information for the districts which does not have the malaria patients information has removed since this will create misunderstanding.

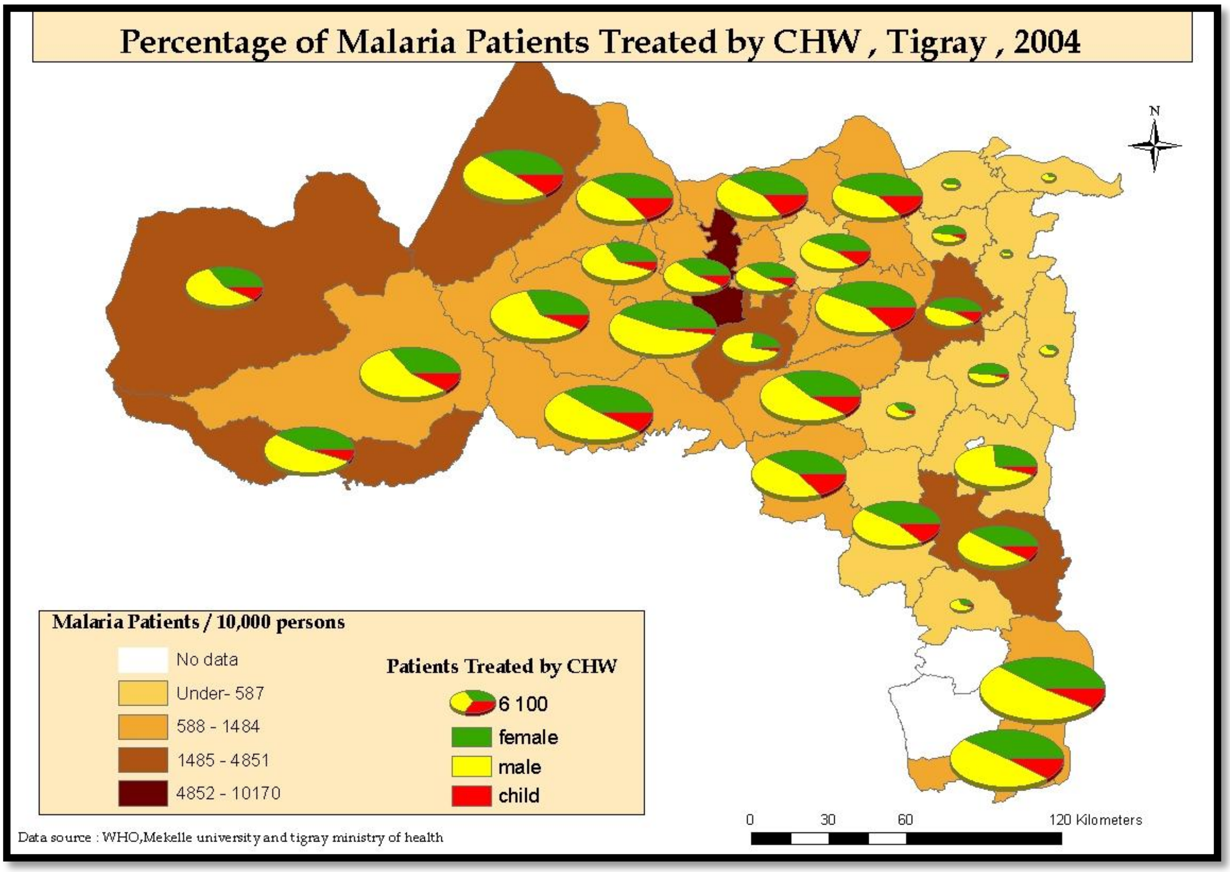

Figure 7.3B Malaria patients treated by community health workers in Tigray region, 2004

MAKEOVER 4

Purpose: The map in figure 7.4A was created with the purpose of trying to show the comparison of malaria situation in the years 2007 and 2008.

Experts' comment: *"Good, but could it be an idea just to display the ratio =cases2008/cases2007 by polygon colors? Color scale could be decided by using the quartiles (did you have a look at ColorBrewer. Some people find it nice to select colors.)"*
In other words the experts suggested that it would be more meaning full if the data was standardized as malaria cases in the year 2008 over the malaria cases in 2007 and represented using color value .

Critiques based on design principles: The data used for the enumeration areas was total which is not appropriate to be portrayed using choroploth mapping technique. It also shows the number of malaria patients for the year 2007 , but not for the year 2008 which creates confusion. No data source information included.

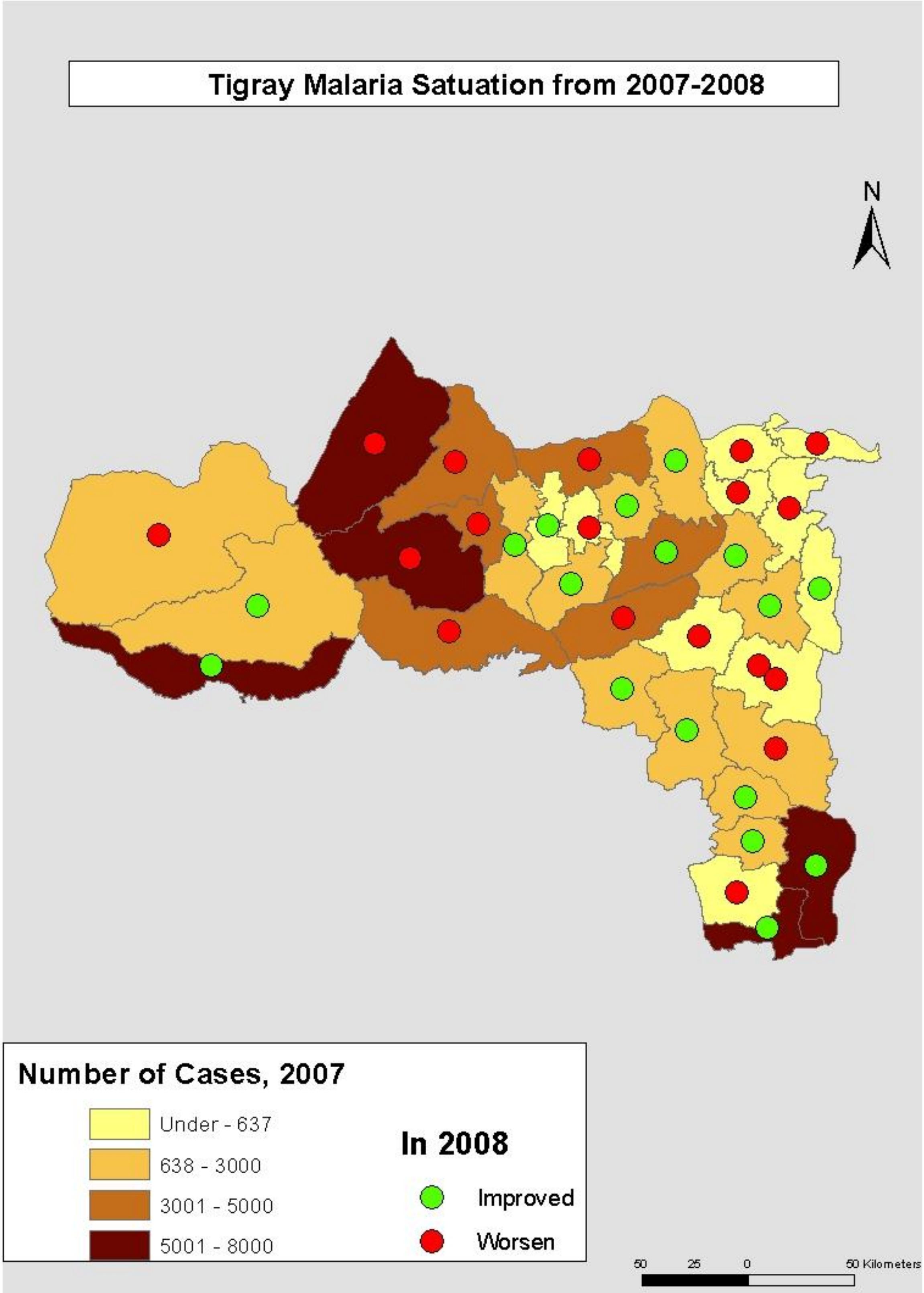

Figure 7.4A Comparison of Malaria incidences between the year 2007 and 2008

Makeover - Figure 7.4B: As the experts commented the data was manipulated to give more information as a ratio of number of malaria cases for the year 2008 to the number of malaria patients for the year 2007 for each district. Interestingly the new map figure 7.4B looks completely different and it also gives more information than the previous map. It shows not only the improved and the not improved once, but also the slightly improved areas. As the experts suggested we choose our color based on color brewer. With white color to show the improved districts, yellow to slightly improved areas and dark red to those not improved. We also add data source information for the map.

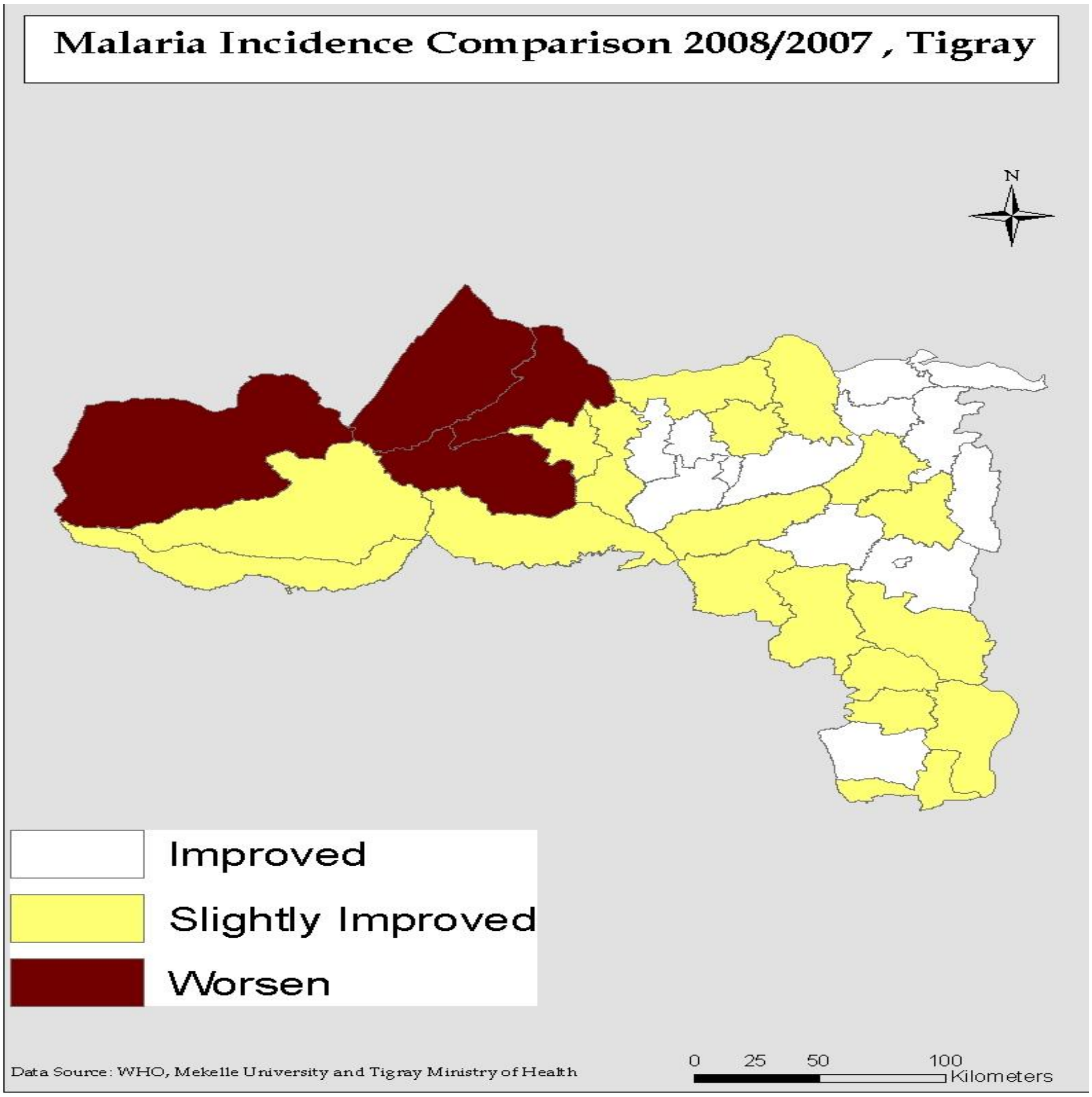

Figure 7.4B a choropleth map showing the trend of malaria incidence year 2007 to 2008 in Tigray region.

MAKEOVER 6

Purpose: The maps in figure 7.6A were designed with purpose of showing trends of malaria in relation to nets distributed for the year 2004 to 2008.

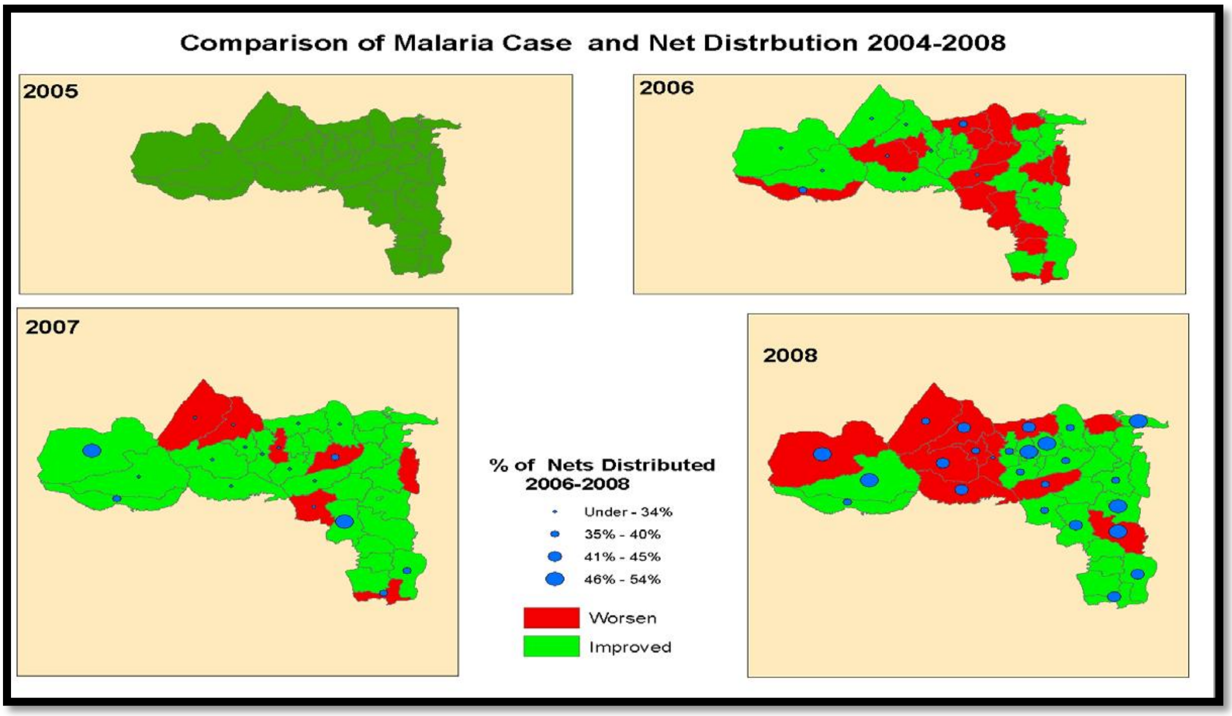

Figure 7.5A The effects of distribution of insecticide treated nets for the year 2006-2008 on malaria incidence (Originally developed map – before comments from experts)

Experts' comment: *"You don't need baseline (2006). Otherwise, really nice one."*

Critiques based on design principles: Figure 7.5A doesn't include data source and direction information. The title is not as visible as it should be .It also does not have scale information .

Makeover - Figure 7.5B: Based on the comments we get we removed the base line which is the map for 2006 ,since it only shows the whole region has improved with malaria situation from the year 2004. On the new map the size of the title is slightly increased and reasonable scale , data source and north arrow are included . A frame has also been included in order to hold all the three maps together and to attract the viewer's attention.

This map is based on the number of nets distributed each year over the number of population since we don't have information for how long a net live.

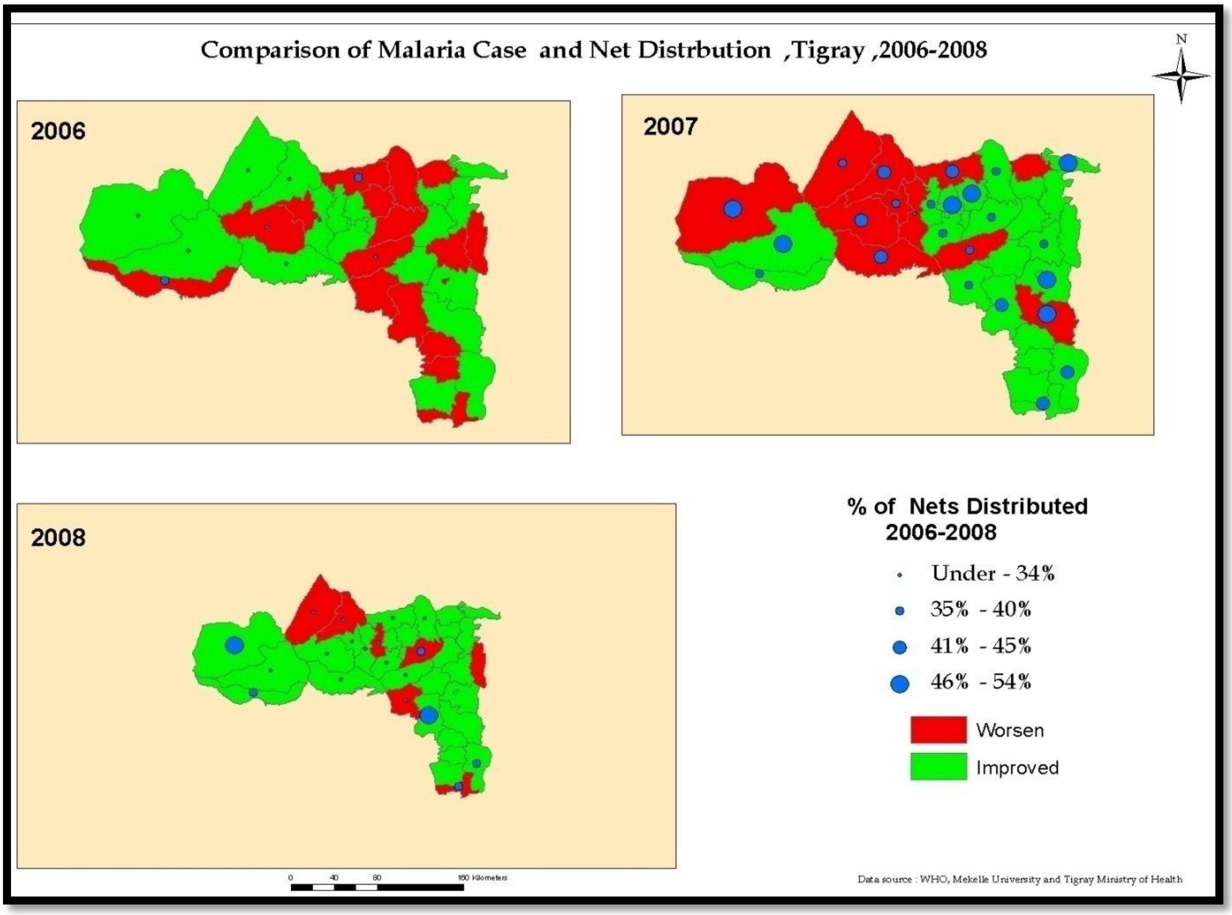

Figure 7.5B The effects of distribution of insecticide treated nets for the year 2006-2008 on malaria incidence (Redesigned based on comments from Malaria experts)

MAKEOVER 7

Purpose: Figure 7.6A was designed with the purpose of showing the trend in malaria situation in relation with the net distribution for the year 2006 to 2008 for the neighbouring districts in western zone of the Tigray region.

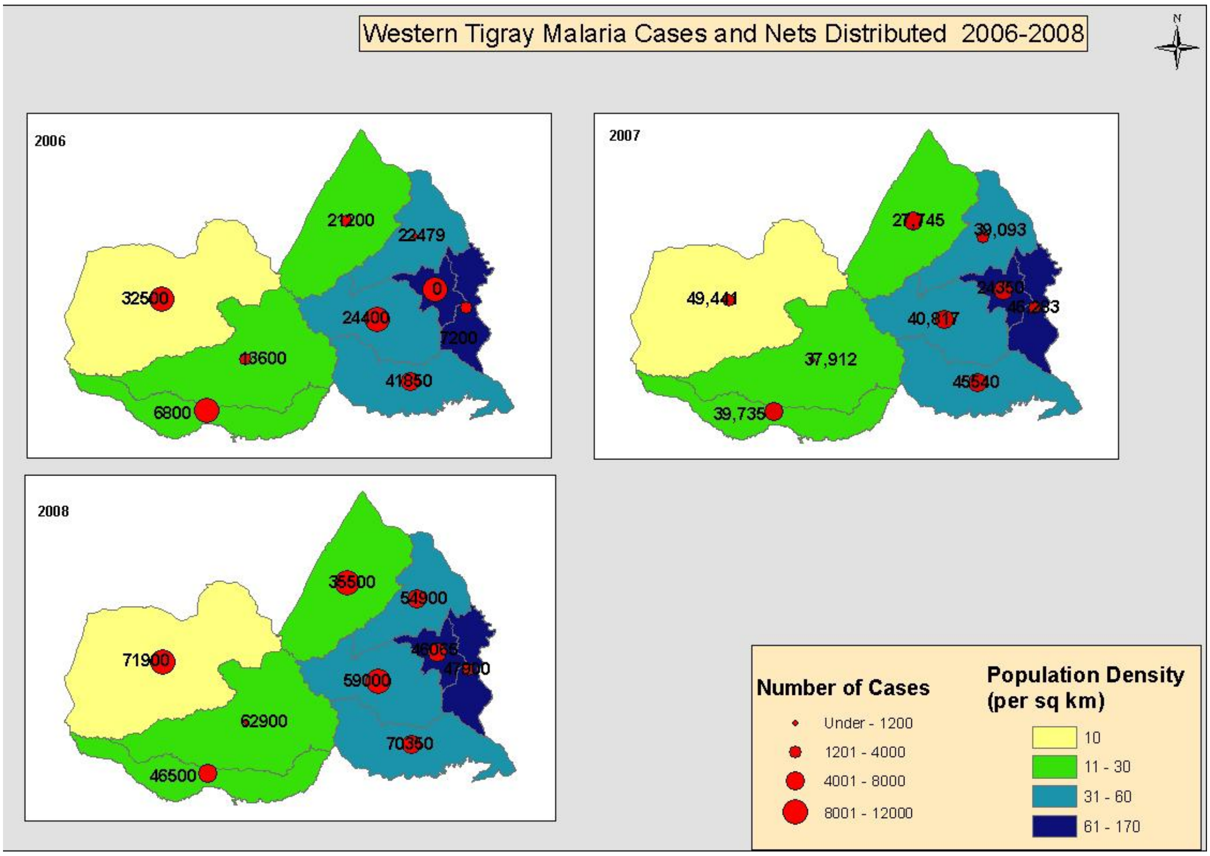

Figure 7.6 A A choropleth map showing the population distribution, trend of malaria incidence and net distribution in the western zone of Tigray for the years 2006 to 2008 (Originally developed map – before comments from experts)

Experts' comment: *"Too much information. Would remove population density or relate it to number of cases. Is the nets a cumulative sum of nets, or new nets distributed each year? in the first case; how long does a net live? How do you choose the interval range, i.e., number of cases/population)"*

To summarize the expert's comments, it was reported as having too much information presented in this map . As we said above the purpose of the map was mainly to show the trend on malaria and the nets distributed in the years 2006 to 2008. There is no logic in adding the population density to this map. Adding the total population might have given more meaning by comparing to the number of malaria patients from the total population rather than adding the population density information on this map. The experts also ask specific questions that should have been somehow explained on the map or by including a description text to explain the map. Some of their questions are, are the nets cumulative sum of nets from previous year or total nets distributed on the specific year; what data classification has been used for the number of cases? They also highlight that we need to answer the question how long the nets live before we decide to map about net distribution.

Critiques based on the design principles: The symbols overlap which makes the map unattractive and also difficult to understand. Moreover, the size of the title is small and the map has no scale and data source information.

Makeover - Figure 7.6B: instead of presenting malaria cases and net distribution information using two different symbols and creating an overlapping problem, we add a line chart for each district which clearly shows the three years trend for malaria cases and net distribution for the year 2006 to 2008. The background information was changed from population density to population per 10,000 persons which gives more meaning in comparing how much of the population in the district has been sick of malaria disease. The size of the title has been increased, which makes it more visible now and scale and data source information are included.

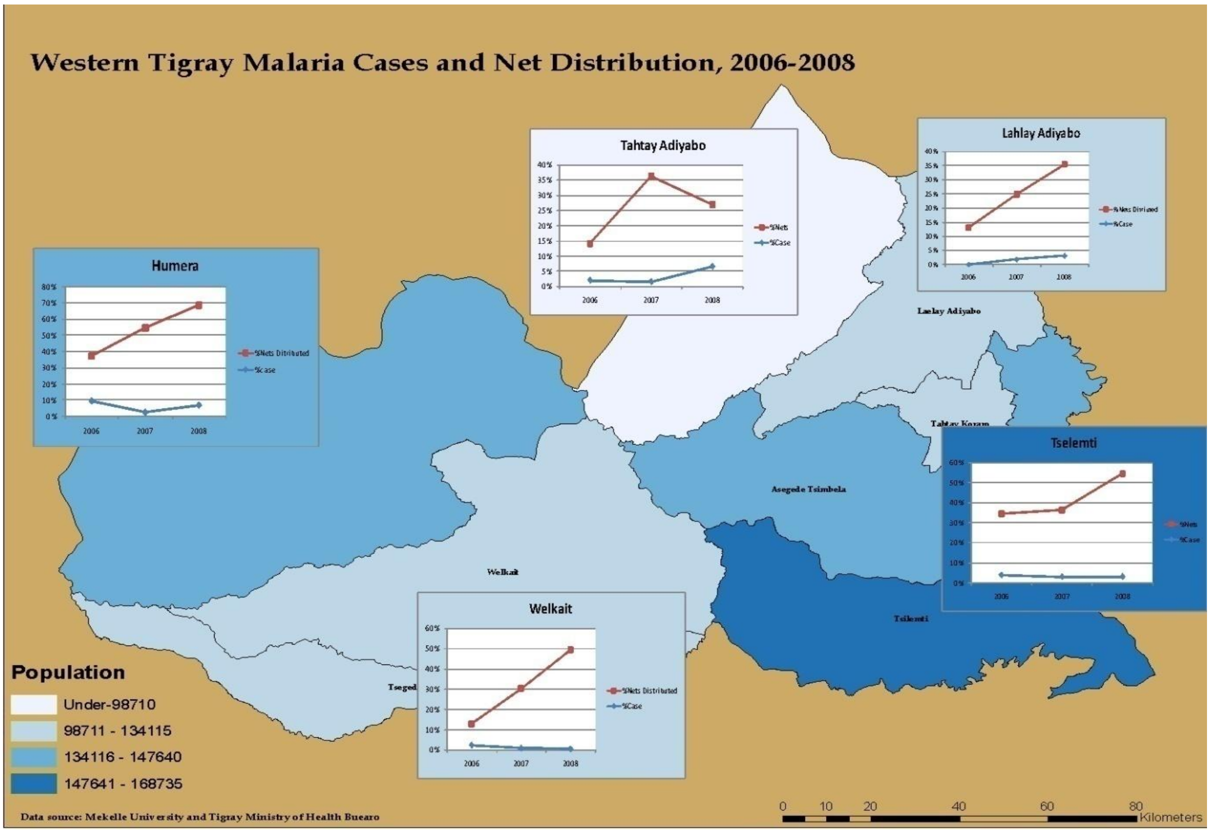

Figure 7.6B A choropleth map showing the population distribution, trend of malaria incidence and net distribution of the western zone of Tigray for the years 2006 to 2008 (Redesigned based on comments from Malaria experts).

8. Summary and Conclusions

8.1. Addressing the Rresearch Questions

Research question # 1: What type of maps can be designed for malaria management program? To answer this question, first we have identified three key issues that need to be addressed: namely, A) what is malaria? B) What are the potential determinant variables in malaria incidence and malaria prevalence? B) Who is involved in malaria management?

A) What is malaria?

Malaria is a life-threatening parasitic disease transmitted by mosquitoes. The malaria parasite enters the human host when an infected Anopheles mosquito takes a blood meal. Inside the human host, the parasite undergoes a series of changes as part of its complex life-cycle. Its various stages allow plasmodia to evade the immune system, infect the liver and red blood cells, and finally develop into a form that is able to infect a mosquito again when it bites an infected person. Inside the mosquito, the parasite matures until it reaches the sexual stage where it can again infect a human host when the mosquito takes her next blood meal, 10 to 14 or more days later (RBM website, accessed 16,01.2011).

B) What are the potential determinant variables in malaria incidence and malaria prevalence?

Even though we don't really know what cause the Anopheles mosquito to be infected in the first place, the most obvious factor influencing the distribution of mosquitoes is the distribution of the breeding site. The distribution of available hosts and the distribution of vector control interventions may also affect mosquito abundance and distribution.

Environmental factors affect mosquito survival. Mosquitoes cannot survive in low humidity, Rainfall expands breeding grounds, *mosquito* parasites are affected by temperature—their development slows as the temperature drops, water-filled irrigation, and swampiness may give mosquitoes another area to breed. Agricultural practices can also affect mosquito breeding areas because farmers use the same pesticides on their crops as those used against malaria vector mosquitoes this might contribute to insecticide-resistant mosquitoes to grow. Modern transportation also contributes to the spread of the disease, moving travelers and occasionally mosquitoes from malaria-endemic to non-endemic regions ((Knols 2009) . Some studies also found out that the of malaria incidence tends to be high in area near water bodies (dams, streams) (Gebreyesus et al 1999,).

How is malaria prevented and treated?

Health care services provide malaria treatment by providing medicine and create awareness on malaria prevention methods on the society. Other key malaria intervention methods are use of insecticidal treated nets (ITNs) , use of indoor residual spraying with insecticide and use of pesticide DDT by people at risk.

C) Who is involved in malaria management?

The main human actors involved in malaria management are malaria control managers, Malaria researchers/experts, top level health managers which are not malaria experts (In our case the federal and the regional ministry of health bureau managers) and the general public.

The type of maps that are needed in malaria management then should include all the above variables in order to be useful and each one of the maps should be designed to be used by all the involved human actors in malaria management or at least by one group of the actors. The question that comes next to our mind will be what types of maps will the malaria managers be interest in? What types of maps will interest the regional health managers in relation to controlling malaria? What about the general public, what would they need to know about malaria and malaria prevention?

Of course there is no a distinct and one general answer for each of those questions. But it is a common sense that the malaria managers would like to know the geographic distribution of malaria in order to help them identify endemic and non endemic areas , they have to know the number of patients treated in relation to those not, they would like to know the occurrence of malaria incidence in relation to what is expected , they have to know the trend of malaria in the region to evaluate and monitor their previous work and their strategies . The malaria researchers would be interested in identifying the cause of malaria incidence and why it is high in some areas than in others. The general public might be interested in knowing the overall situation of malaria in their areas and where they can find treatment and information.

Based on the above background four main types of maps that is useful for malaria management is identified in this study. Those are

1) *Incidence maps* – Maps that are designed to show the geographic distribution of malaria incidence and prevalence (See section 6.4 for examples). Those maps can be used by researchers to investigate the source of the disease and why it is high in some areas.

2) *Trend maps* – maps that show the change in time in malaria incidence and in malaria controlling measures. Those maps are useful to evaluate and monitoring previous work in malaria management program. The study has also tried to show different ways of showing trends in a map. (See section 6.2 for detail)

3) *Cause and effect maps* –The purpose of those maps in this category is to find out if any relationships exist between malaria incidence/prevalence and the potentially related variables that are discussed above either in minimizing or maximizing the number of cases (see section 6.3) . Those maps can help in tracking the cause of the disease and based on this the malaria managers can respond more effectively by identifying the relevant population at risk.

4) *Health service maps* - maps that are designed to show any health service information in the specific area. Those maps are useful for health managers, for malaria managers and the general public. The maps provide information for health managers to see where they need to build more health facilities. The general public can be benefited from those maps to find information on where to go for treatment or for information. The malaria managers can use those maps as a planning aid tool on allocating resources a head for those areas which are far from the health facilities (see section 6.1 for detail).

Research question # 2: **How can the maps be designed effectively & efficiently in order to convey the proposed message?**

An attempt to answer this research question required addressing the following basic issues:

- What is a good map design?
- Why is it essential to give proper emphasis to technique of a map design?
- What do we mean by effective and efficient way of designing?

What is good map design?

There is no perfect map and not all cartographers will agree on all aspect of the specific map design, however one should strive to create the best map possible given his/her skill, available data and equipment (Dent,1999). But there is a bad map.

A good map is a map which communicates well with its audience. Most importantly good maps are those which meet their intended purpose and become useful for the intended audiences which are designed for in the first place. There are two types of maps general and thematic maps (specific purpose maps). The maps designed in this study are thematic maps which are designed with a specific purpose which is to assist in the work of malaria management and for a specific group of intended audience (malaria managers, health managers and the general public). But for any map whether it is a general purpose or a specific purpose map, there is a discipline that guides on the design of those maps. This discipline is called cartography, defined as the art and science of maps. In cartography there are map communication models which contain basic steps involving in communicating map information to others (Sloccum 2009, Robinson 1995).

For this study, we adopt map communication model with a set of five idealized steps from Sloccum et al.(2009) .Those five steps include considering 1) the real world distribution of the phenomenon to be mapped based on previous experience and knowledge, 2) determining the purpose of the map and the intended audience, 3) then collecting the appropriate data to be mapped , 4) actually design and constructing the map which involves important procedures that determine weather the map will be a good map (a map which meets its intended purpose) . Those include, choosing appropriate map designing technique, choosing appropriate data classification methods, choosing the appropriate scale and map projection for the purpose of the map and choosing the necessary map elements to be employed on the final map. The last step on the model we used is also a very important which will help us to evaluate the goodness of our map which is step 5) determining whether the intended users find the map useful and informative . This is done based on getting feed back from the intended audience of the map and then incorporates their needs, comments and all in all their feedback on the final map design.

Why is it essential to give proper emphasis to technique of a map design?

Well it is easy to lie with maps (Monmonier, 1996). According to monmonier, “maps, like speeches and paintings, are authored collections of information and are also subject to distortions arising from ignorance, greed, ideological blindness, or malice.” But in our case taking that risk in presenting health information will be dangers. Since health related information is very sensitive, we need to be careful on presenting our data. Our map presentation should give the correct message and also the correct impression even at first sight. For example maps in figure 8.1 shows the use of appropriate data with appropriate map designing technique. It shows how wrong choice affects the message of the map and creates misunderstanding.

Figure 8.1A and 8.1B show the same information (distribution of malaria incidence) but in different data formats. While the former shows the incidence in terms of per 10,000 population, in Figure 8.1B, the incidence is described in terms of total number of cases. Figure 8.1C show the population distribution of the districts. Comparing the Tahtay Michewu and Adwa districts, one can simply notice that Tightay Michaw is more densely populated than Adwa district in all the three maps displayed in Figure 8.1.

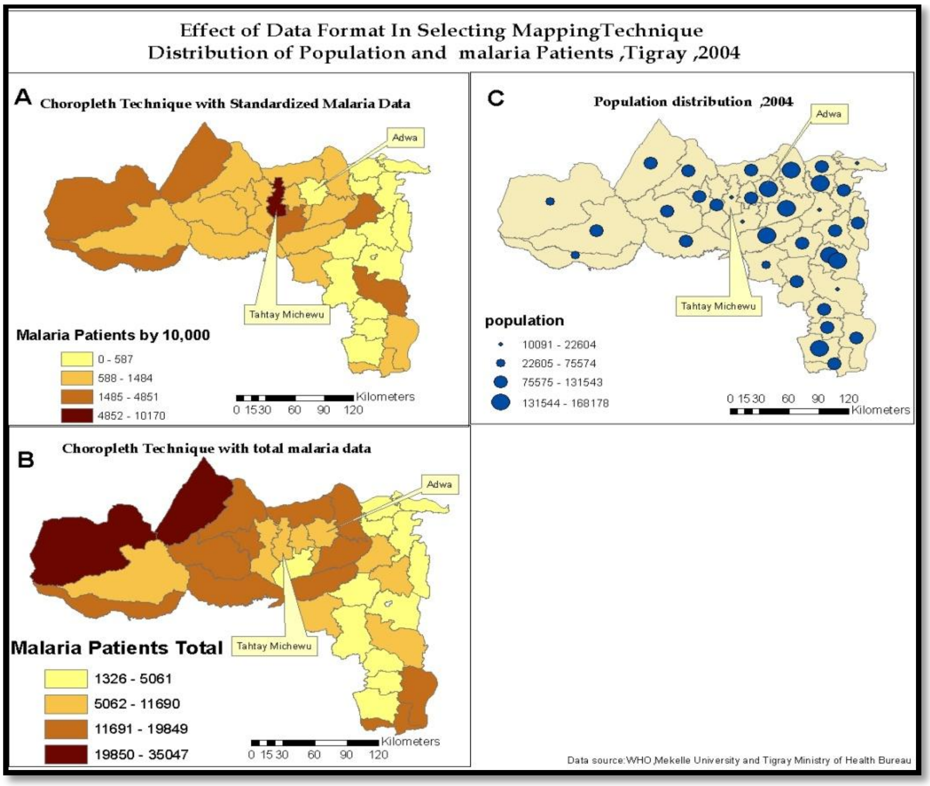

Figure 8.1 the Effect of Data Format in Choosing Map Design Techniques

On Figure 8.1 B both districts are color shaded the same ,.which is wrong and can mislead the malaria managers not to give priority to Tahtay Michewu which have the highest malaria cases and need immediate intervention , but when we standardized our data as per 10,000 population as in figure 8.1 A, the maps shows the severity of malaria in district Tahtayy Michewu by coloring the district the darkest color in the class range (the one which shows highest number of malaria).

Knowing the nature of the intended audience (the end users of the map) also plays an important role in designing a good map. Maps designed for novices (people who are new to the map's subject) should be more explanatory, simple, clear but informative. Where as experts on the subject of the map expect more substance, with more variables, and expect to engage with a complex map. A multivariate map for malaria experts/researchers which visually interpose three data variables related to malaria research as in Figure 8.2A (Health service catchment area, villages and malaria incidence) might put off the village farmers (a group of the general public) by its complexity . Village farmers need to know the malaria conditions in their village, but they are not trained researchers. They need a malaria incidence map designed for them to help them learn about the malaria condition. Figure 8.2B might be appropriate for map for the farmers than Figure 8.2A.

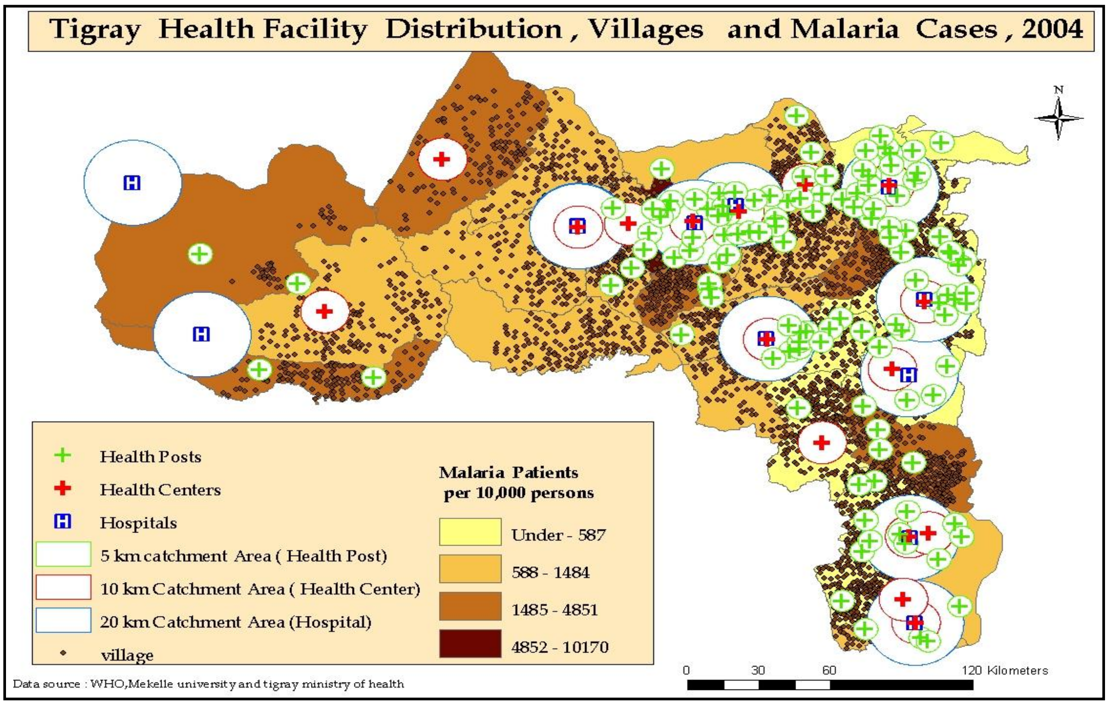

Figure 8.2 A multivariate malaria incidence map in relation to catchment area of health facility distribution and villages outside of the catchment area.

This map is useful for malaria researchers to help them investigate if their is a relationship between the visually interposed variables. But for most group of the general public (e.g. farmers) can be put off by the maps complexity.

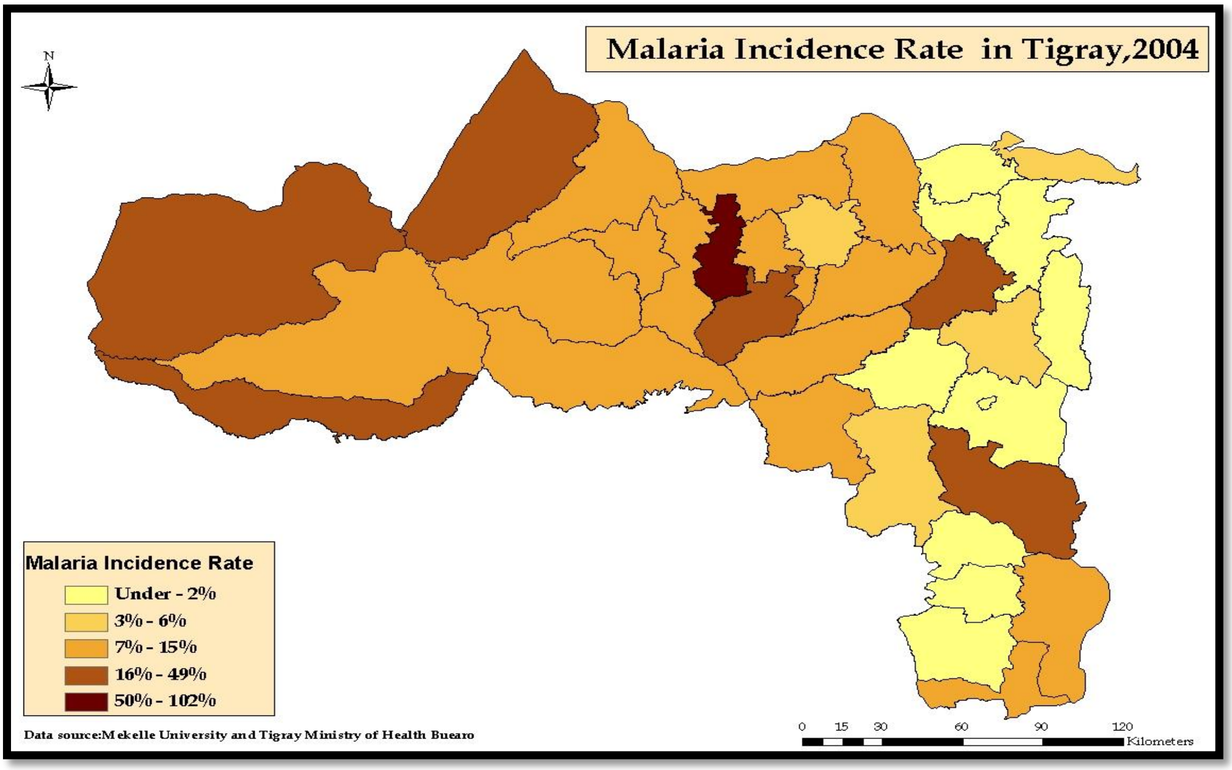

Figure 8.2 B Malaria incidence map of Tigray, 2004. This is simple and clear map with one variable.

The general public for example farmers in the region might prefer this map than the map in 8.2A to know the malaria condition in the region.

Another best and ideal way of designing a good and effective map is by involving the end users idea in the design process. In the case of maps this can be done by receiving feedback on the initial design of the maps and incorporating the comments on the final design. This way the maps it will be possible to assure the users needs and to design a good map .If the end users do not find the map useful and attractive, then the map is not good at all. For example Figure 8.3A was one of the initial maps we designed in the 'Health Service' maps category. The purpose of the map was to access the distribution of health facilities in the region in relation to population density and malaria. The feedback received from one target audience (malaria experts/researchers) on the map in general implicates that the map was not clear with its massage. Their comments include questions like *1) What is the need of having the catchments areas unless they show population information inside the catchment area 2) if the purpose of the map was intended to show malaria situation in the region , then why showing population density instead of total population ? .* This shows that the map is not good enough to convey its message correctly. In other word as designers we did not succeed on creating a map that communicates well to the end users.

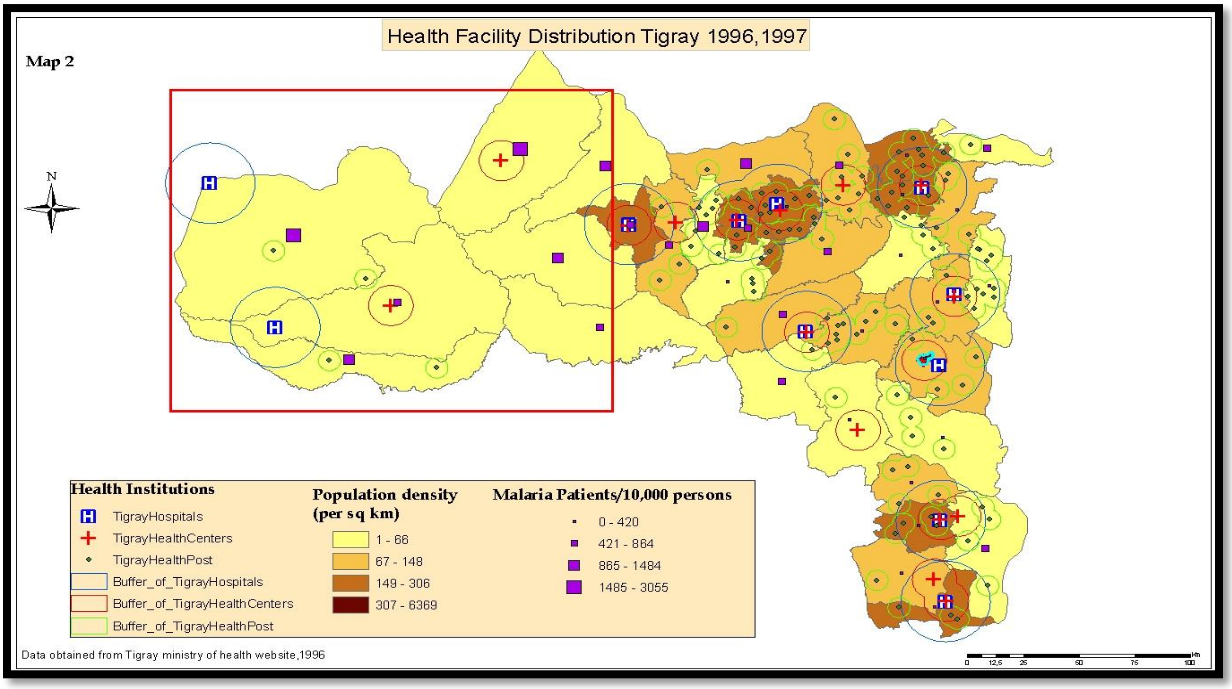

Figure 8.3A Distribution of health institutions in Tigray region in relation to population density and malaria cases /10,000 populations.

One group of the intended audience (Two malaria experts from Norway) do not find this map clear to understand its purpose.

As the experts said it, one reason that creates a problem on the clarity of the map is because it contains too much information (variables) that are not clearly dependent (catchment area & population density). The map redesigned to meet the users needs by incorporate their feed back. Based on the comments, two different maps produced. The first one to show the malaria situation in the region in relation to health service catchment areas (Figure 8.3B) and the second map to show the distribution of the health facilities in relation to population density (figure 8.3C). Now it is easy for the users to understand where there are health institutions in the region and where it is thin in the ground based on figure 8.3B .They can also access if their are more health institutions in densely populated areas than in non densely populated areas with the same map .

The redesigned map on Figure 8.3C also clearly shows how much of the villages are out of the catchment areas of the health facilities. As it shows in the map there seem to be a correlation between a mass number of villages outside the health institution catchment areas with areas which have high malaria incidence in the region. Malaria researchers can use this information to lead them for farther investigation to confirm it.

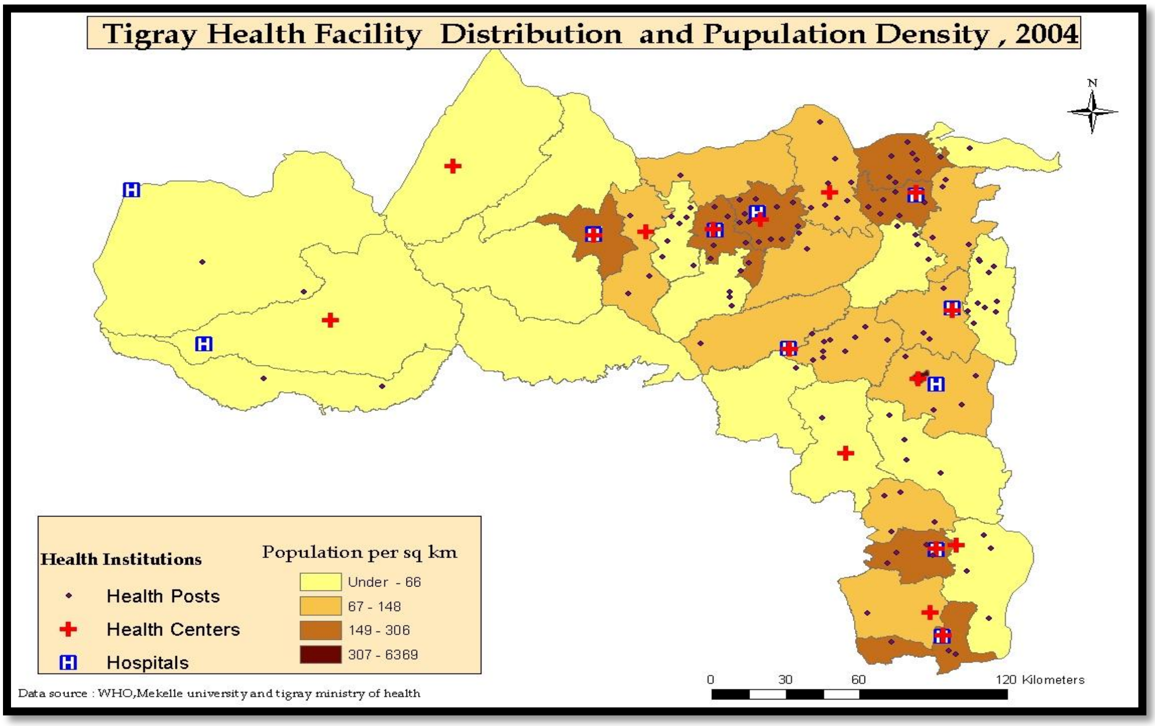

Figure 8.3B Map to assess the distribution of health institutions in relation to population density (A map redesigned from figure 8.3A based on comments from malaria experts).

Selecting appropriate map symbols and map elements plus positioning them appropriately have also a huge effect in designing effective (good) map. Map elements (e.g. Title, Legend, Scale, data source information) and symbols (e.g. Colour, circles, form) represent the building block in cartography: the transmission of geographic information through the use of maps (Slocum et al. 2009). A map should contain at least the basic map elements and they should be positioned reasonably. Reading a map is like reading a page in a book .Most map readers scan the entire map starting from the upper left to end in the lower right (Krygier and Wood, 2005). So it is best to position those map elements that should be seen first in the upper left part of the map.

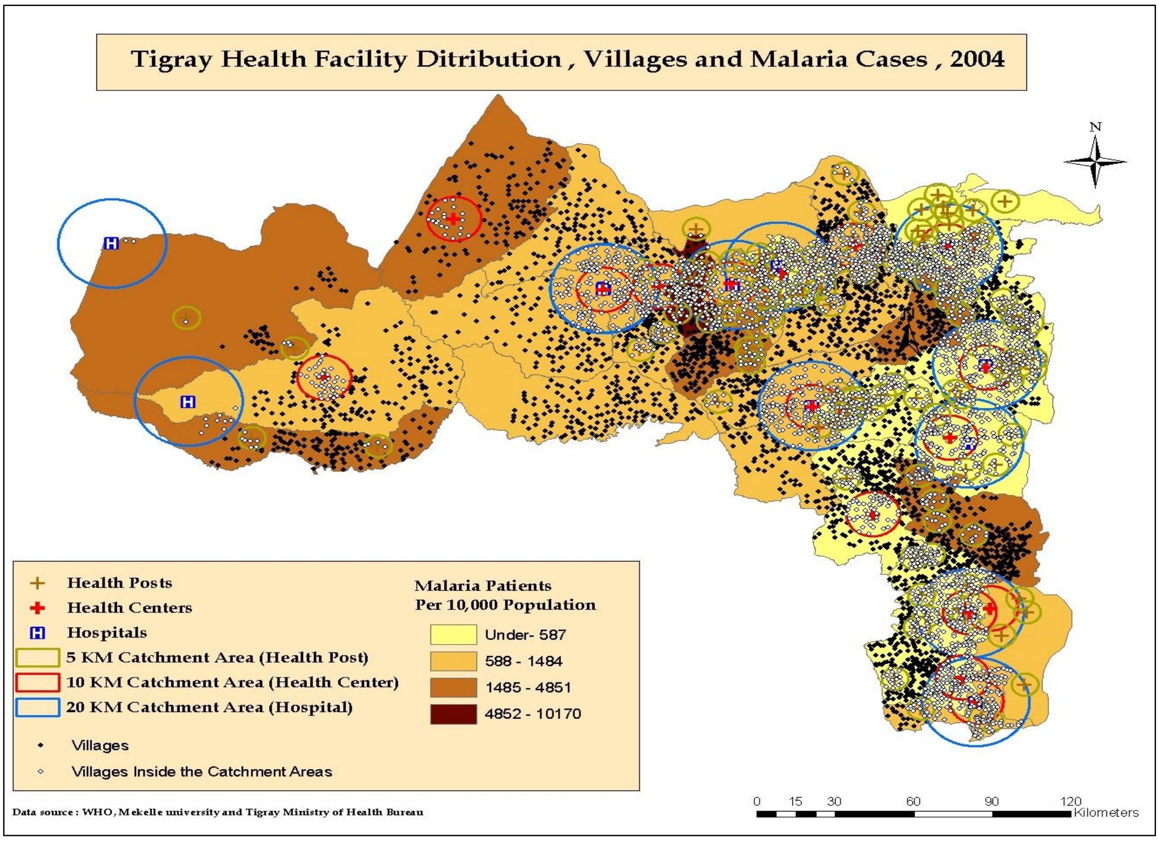

Figure 8.3C Malaria Incidence, village distributions and catchment areas of health institutions (A map redesigned from figure 8.3A based on comments from malaria experts).

The above map is designed to assess the catchment area of Health institutions in relation to village distribution in the region, and to see if malaria incidence is more in those villages outside of the catchment areas.

Symbols in the map should be clearly visible. Overlaps should be avoided. For example figure 8.4 was one of the trend maps we initial designed to show the trend of malaria incidence in relation to insecticide nets distribution for three consecutive years from 2006 to 2008. As the map shows the graduate symbols which was chosen to portray number of malaria incidence and the labelled values for number of distributed insecticide treated nets are overlap on the map. This makes the map unattractive and messy. Most importantly since the label for the number of nets distributed are invisible, the map readers will face difficulty in understanding the map. In fact it might not even communicate at all because of this. The malaria experts also commented on this and as they put it *“Too much* *information. Would remove population density or relate it to number of cases and avoid overlaps ".*

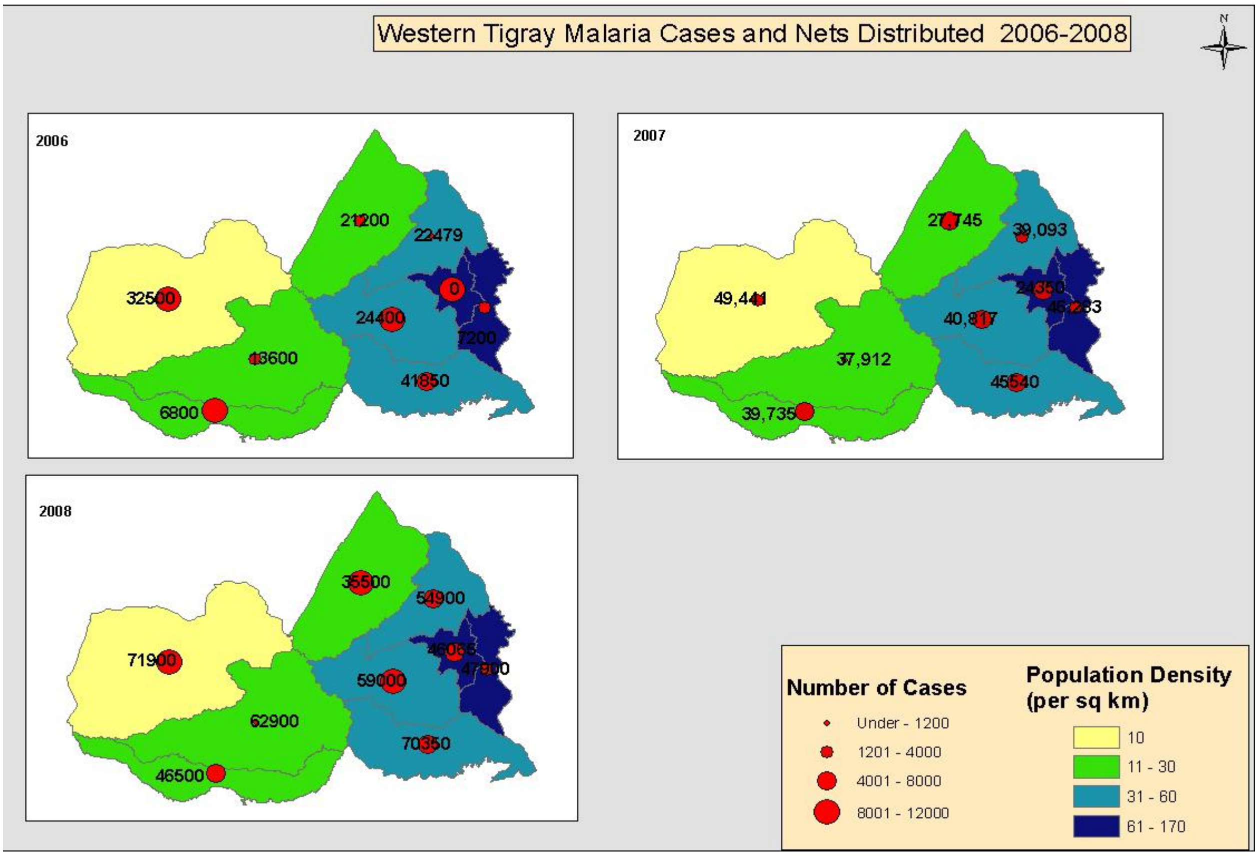

Figure 8.4 A is initially designed map A trend map showing the malaria incidence and distribution of ITNs in western Tigray ,2006 to 2008

The symbol overlap on top of each other makes the map less attractive and a bad map.

As the nature of those target groups (malaria experts) know a lot about malaria, designing a map with various variables is not the problem. The problem with the map in figure 8.4 was the way it was designed and represented by overlapped symbols. On redesigning the map multivariable nature of the map is kept, but presented in a more clear way. As It shows in Figure 8.4B trend of nets distributed and malaria case are drawn in a line chart, which is a commonly chart on showing trends. Then the line chart is interconnected with the base map of the western zone via shading the same colour for both the line chart and the population density information for the each of the district. The colour shade for population density in a specific district on the map is the same as the background colour of the line chart for that district which shows the nets and malaria cases trend of the district.

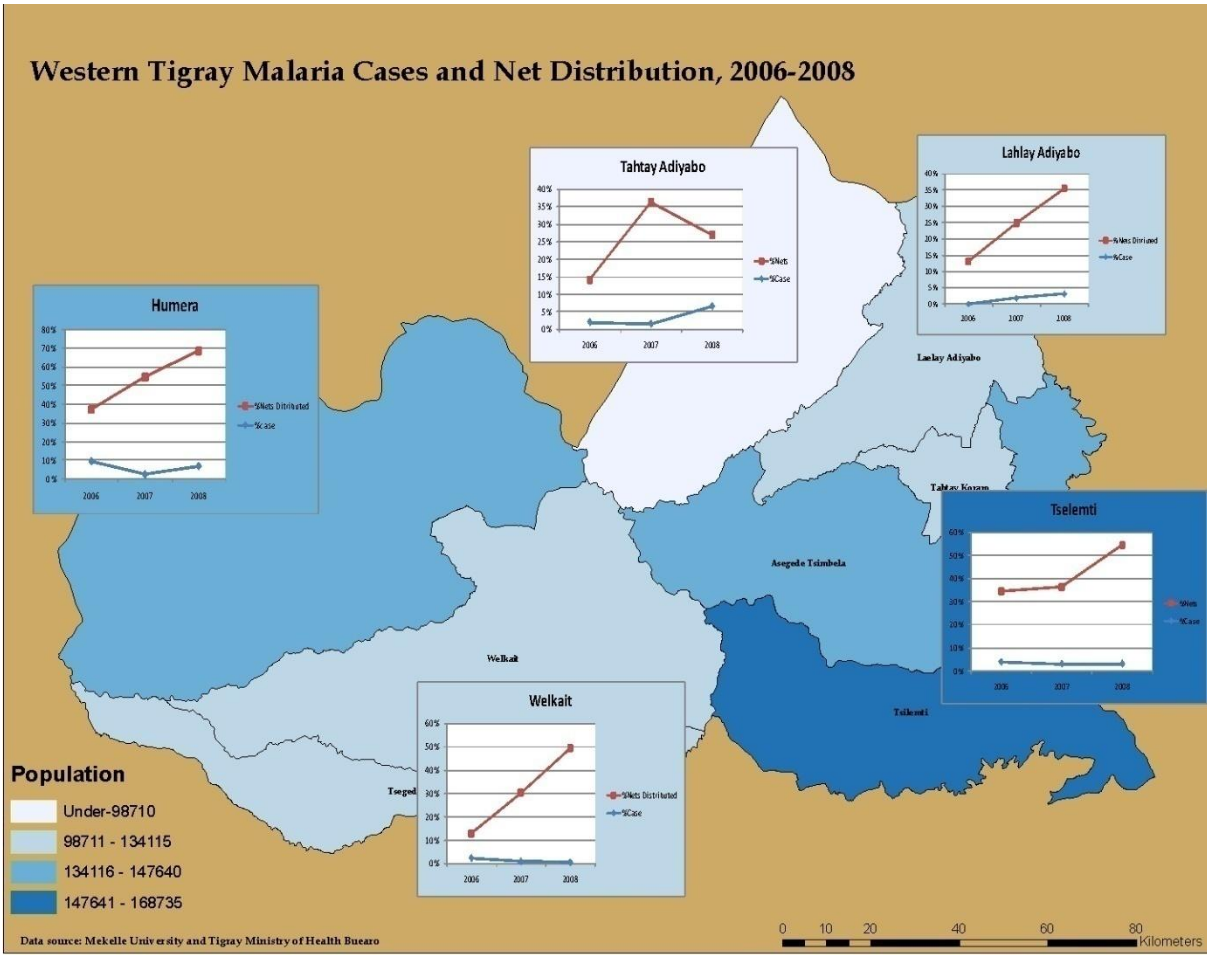

Figure 8.4B The maps shows the trend of malaria cases and net distribution for the year 2006 to 2008.

This map shows the trend of malaria cases and net distribution for the year 2006 to 2008 with line chart and population density information using choropleth mapping technique using colour value shading dark blue for densely populated districts and light colour for lass populated districts . This map is a more clear and organized than the map in figure 8.4A.

To perform a comparative analysis of the different map techniques applied in this thesis, we borrowed two maps (Figure 8.5 & Figure 8.6) from the 2006 Tigray regional health bureau annual health profile report (TRHB-AHPR, 2006) and from a student masters on mapping malaria (Nhavoto,2009) respectively . As indicated in the regional health profile report, the purpose of the map in figure 8.5 was meant to show the postnatal coverage in Tigray region for the year 2006.

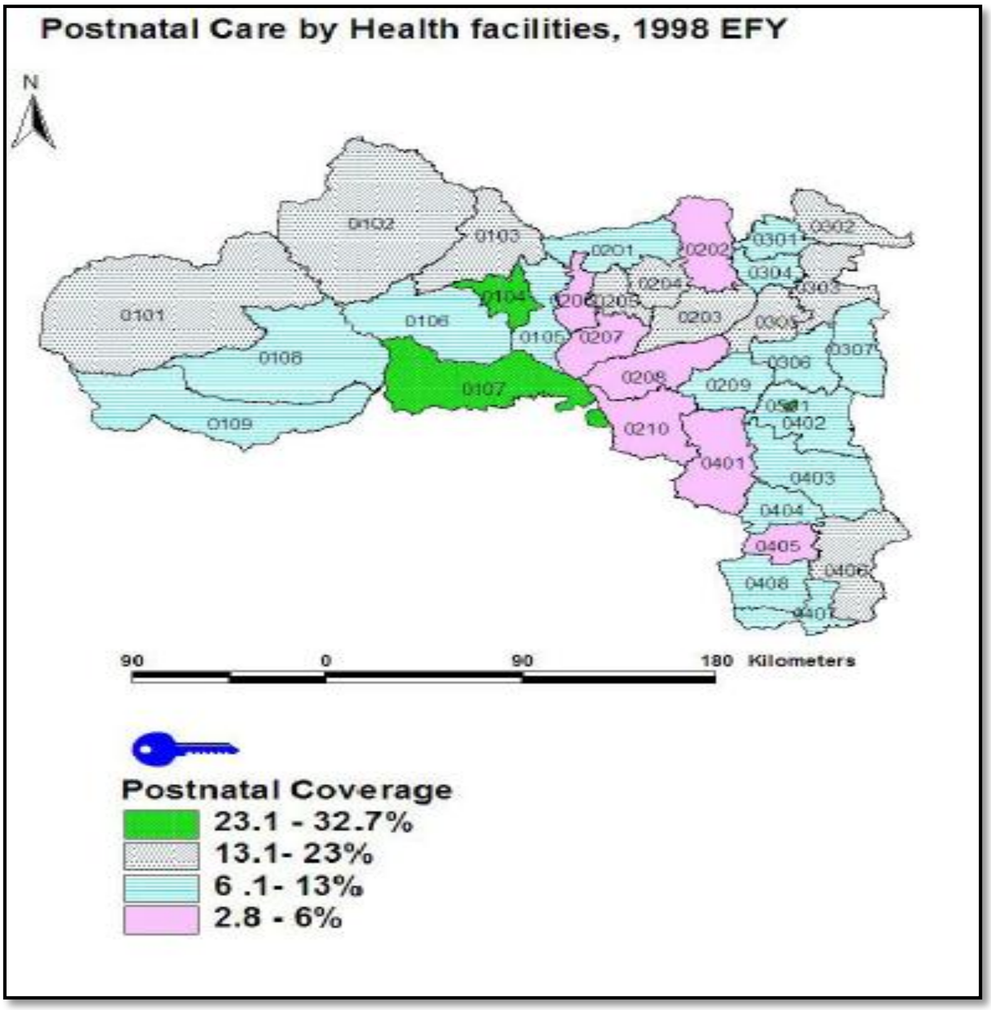

Figure 8.5 Postnatal coverage in Tigray for the year 2006 (source : TRHB-AHPR, 2006)

The most important critics on the design of this map are the color choices. On the first sight of the map, the impression one may get is either the green color shaded areas are with high postnatal coverage and the grey areas with least postnatal coverage or vise versa. Theoretically, when one designs thematic maps, the goal should be to choose symbols that are intuitive to the map reader (Krygier & wood, 2005). Thus, with quantitative data, low values should be light color and high values should be dark color (*ibid*). Accordingly, the above map should have been colored with color values as darker color shading districts with high postnatal coverage and lighter color shading districts with lowest percentage of postnatal coverage. Those areas that lie in between in terms of the coverage could have been colored in a respective order of the color value. The second possible critiques could be on the title as it is not explanatory enough. A title is the most important element of a map and it should succinctly reflect the maps theme. In figure 8.5, we found the title of the map to be ambiguous as the title '*postnatal care by health facilities*' is not clear enough to identity whether the map is all about: 1) locations of postnatal care service; or 2) postnatal care coverage.

Moreover, we found the key symbol on the top of the legend heading to be unnecessary and confusing. Since the heading of the legend is already written as postnatal coverage, the key symbol is unnecessary potentially causing the designing of the map to be less efficient (time and space wise). Of course scale is necessary on designing any map, but it shouldn't be that visible unless it is necessary. Since there is nothing to be measured in the map this much scale visibility is unnecessary. The most important map elements are the title and the legend and those should be the once which should attract the map readers attention than the scale or the north arrow. The map could have been look a bit nicer as well as had it have been inside an inset/frame line which holds the entire map and its symbols. All in all mainly because of the color choice this map might not communicate its message correctly to the map readers or the map readers will be required to do extra effort to understand it by looking careful at the legend.

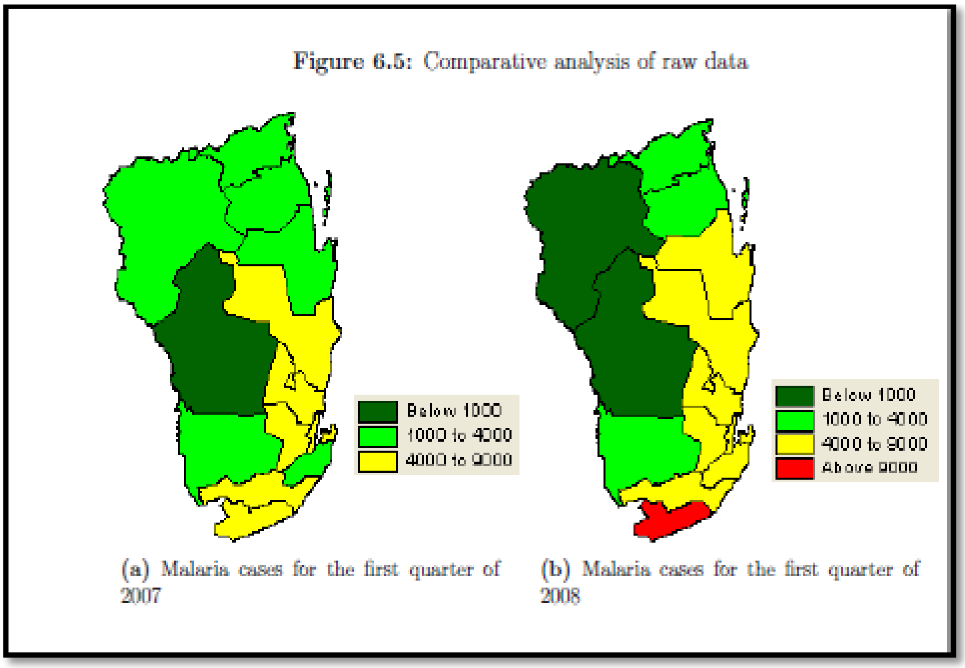

Figure 8.6 Comparison map showing malaria cases for 2007 and 2008[9].

[9] Source: Nhavoto, 2009

The worest error of the map in figure 8.6 is 1) The color choice have no logic. The lowest values states are dark green (darker than any of the colors used on the map) which would normally be used for high values, the lowest value on figure 8.6 states as yellow which is normally used for low values. This map most likely be misunderstood by the map readers, in fact the readers might understand the maps message quite the opposite. As the areas shaded in dark green endemic to malaria and the yellow shades with less malaria incidence. Additional errors in this map are, 1) the map title is not explanatory and the name of the mapped area is unknown. 2) No data source information stated for the readers to determine were the data is obtained. 3) No scale information- it will be difficult for the reader to know how much reduction has been taken place on the mapped area.

What do we mean by effective and efficient way of designing?

Designing effective maps means designing maps that meet the intended purpose and be useful for the intended audience. What makes a map to be an efficient map is when the maps is designed in a way that can be produced and replicated easily with a fairly less complication and time requirement. In this study we designed maps that are useful for malaria management and those maps should help the malaria managers, the health managers and the general public in making the right decision. The map designing principle in the map communication model guides us in designing effective maps. The maps also being commented by one of the target group and found out their usefulness for the purposed designed for. During the whole process of producing all the maps included in this study, we believe that our adherence to the map designing principles and techniques and detailed dialog with a target group (Malaria experts in Norway) make our maps to be efficient maps as they can be reproduced and replicated easily.

8.2 Previous studies and the gap

The application of GIS ,remote sensing , GPS and GIS mapping technologies in general are becoming popular in monitoring and controlling malaria and their usefulness is no longer in debate. In fact some researchers even argue the GIS are the best information system in our generation for malaria research and control (Takken et al., 2005 &Bertas 1996**)**.

Sipe & Dale (2003) have done literature review on the current use of GIS in malaria research and control program and organized their literature findings into five categories as outlined below.

1) For mapping malaria incidence/prevalence over some geographic area. (MARA,1998 , Kleinschmidt I,2000, snow RW,1999. 2) For mapping the relationships between malaria incidence/prevalence and other potentially related variables including, temperature, rainfall, elevation; demographics (age and gender) population movement, climate change, breeding sites and control programmes. In most cases these studies involve testing to see if any statistical relationships exist (Martens p, 2000), 3) Using innovative methods of collecting data. For the most part this literature deals with remote sensing in the form of aerial photography and satellite imagery to collect data (Hay s et al.1998,Tanser F et al,2002).
4) Modelling malaria risk: This literature is future-oriented and focuses on predicting areas of malaria risk. Risk models typically use many of the same variables discussed above – the difference is that statistical relationships are established between malaria incidence/prevalence and the potentially related variables in an effort to predict future cases of malaria (snow RW, 1999)

At the end of each and every one of the above studies different maps are produces in order to present their study findings , however to the best of our knowledge there is no a complete study that have been done in identifying and developing useful types of maps in malaria research and control program. In addition to that, still to the best of our knowledge there is no study which tried to show map design principles and practices in the output of GIS mapping particularly in malaria field. As we have discussed above maps can misinform the decision makers unless designed carefully.

8.3 The contribution of this study

The general contribution of this study is it gives an over all guide in how GIS can be used in malaria management, in the sense that this study has identified the main types of maps that are useful in malaria management. Since maps are the result of GIS analysis, indentifying the needed maps can guide on how and for what purpose GIS technology should be used in malaria field. Knowing the maps needed in malaria managements leads to identify the problem. In addition to identifying useful types of maps in malaria management, this study also shows different way of designing maps. It shows different kind of trend maps, different kind of cause and effect maps.

The specific contributions can listed as three as outline below

1) It emphasises the need of a careful map design at the end of the GIS analysis. GIS software are full of default settings , but as we have been discussing through out the thesis un logical choice of mapping techniques, data classification methods , colors ,symbols lead to a big miss understanding and it might even be dangers , since health related information is sensitive. The study also emphasises the importance of including user comments and feedback on the way of visualizing data particularly in maps.

Most importantly, this study can serve as a policy guidance to the Tigray regional State in assisting malaria control and prevention program, because the maps developed in this study provides important and accurate information to malaria management, to health managers in the region and to create awareness to on the general public .

In addition to that, Literatures like Tanser & Sueur (2002) found out that most health related applications of GIS were done in South Africa and this raise questions on the level of its application in other Sub Saharan Africa nations. So this study can contribute to literature about GIS and GIS mapping in Ethiopia particularly in malaria research.

8.4 Limitations of the research

Some limitations of this research and some difficulties faced during this study are listed under

- This research is based on secondary data and desk research because the author has personal reason that makes her not able to go to field work and do action research. This creates a problem in understanding the exact needs of those involved in malaria management (intended audience).
- Although it was originally intended to design some more maps which require advanced GIS analysis and with more potentially related variable for malaria management (E.g. Using evlevation, temperature, and rainfall data), most of the applications developed in this study are rather simple because of data limitation and time limitation.

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